

# New Results from ATLAS

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Fermilab Wine & Cheese Seminar  
April 8, 2011

**ATLAS**  
**EXPERIMENT**

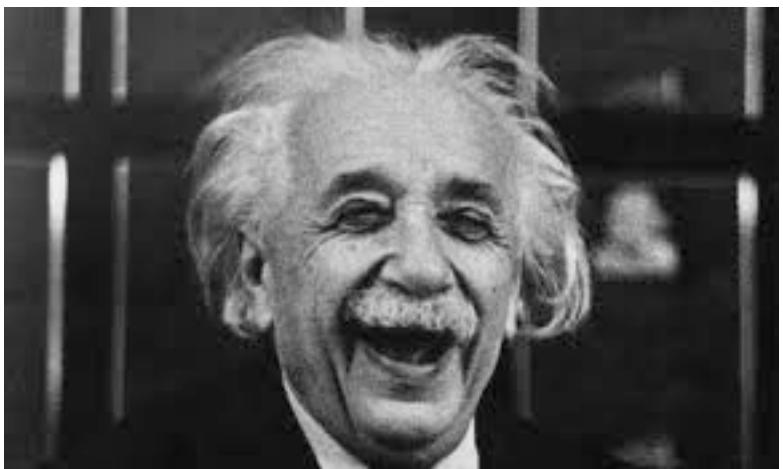




# Our Pursuit



Understand the nature of  
**fundamental particles** and their  
interactions, and of space and time



**Gift from Einstein:** energy we impart to  
colliding objects can be used to create **new**  
**forms of matter**





# Large Hadron Collider and Experiments



ATLAS

ALICE



LHCb

France

CMS

Switzerland



# The LHC Delivers, ATLAS Collects

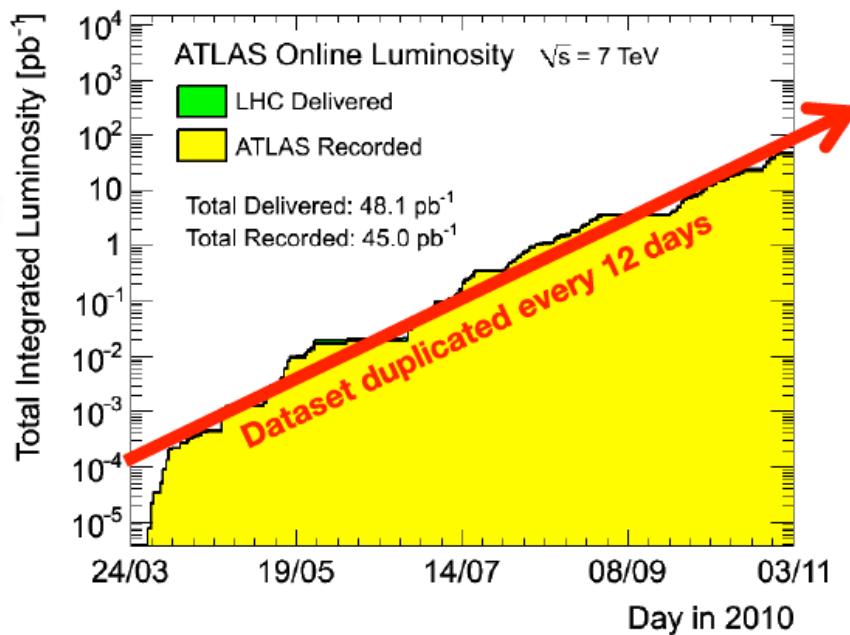
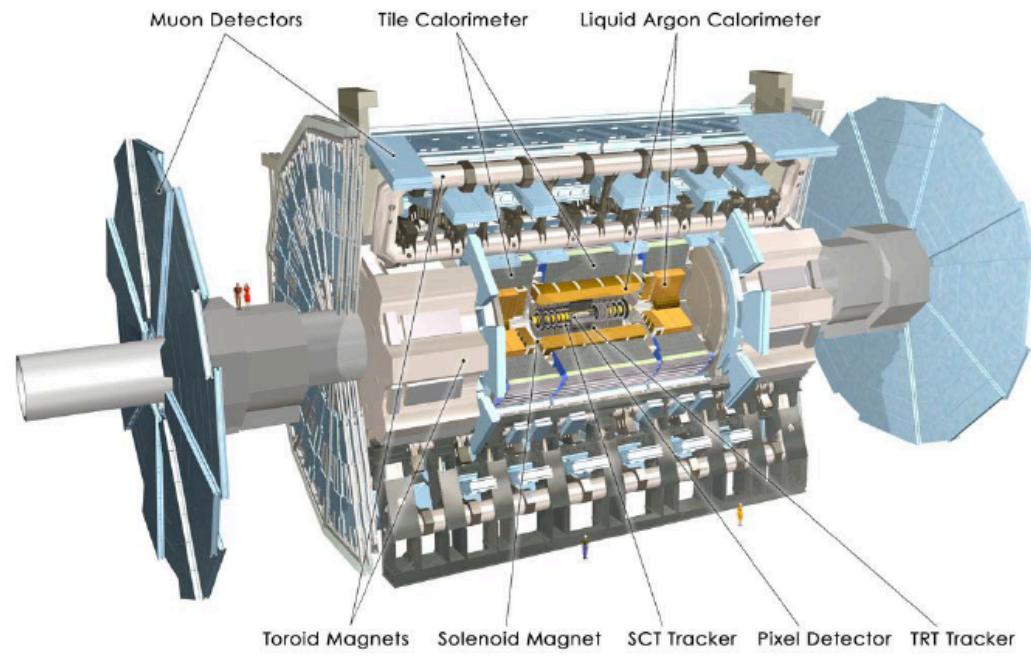


## ► Data collected in 2010 (pp collisions at $\sqrt{s} = 7 \text{ TeV}$ )

- Peak lumi  $2.1 \times 10^{32} \text{ cm}^{-2} \text{ s}^{-1}$
- Pile-up now up to  $\langle n_{\text{vtx}} \rangle = 4$
- Single lepton triggers  $\sim 35 \text{ pb}^{-1}$
- Lumi uncertainty down to 3.4%

Inner Tracking Detectors			Calorimeters			Muon Detectors				
Pixel	SCT	TRT	LAr EM	LAr HAD	LAr FWD	Tile	MDT	RPC	CSC	TGC
99.1	99.9	100	90.7	96.6	97.8	100	99.9	99.8	96.2	99.8

Luminosity weighted relative detector uptime and good quality data delivery during 2010 stable beams in pp collisions at  $\sqrt{s}=7 \text{ TeV}$  between March 30<sup>th</sup> and October 31<sup>st</sup> (in %). The inefficiencies in the LAr calorimeter will partially be recovered in the future.





# Reconstructed Objects

- Detector data → inferred physics objects
- Try to fit puzzle pieces together to find plausible hypotheses about the physics behind the collision data we collect

## Jets:

- Reconstructed from 3D topological clusters
- anti- $k_T$  algorithm w/ size parameter  $D=0.4$

## Electrons:

- Inner detector track matched to EM calor cluster
- Isolation to suppress fakes

## b-Jets:

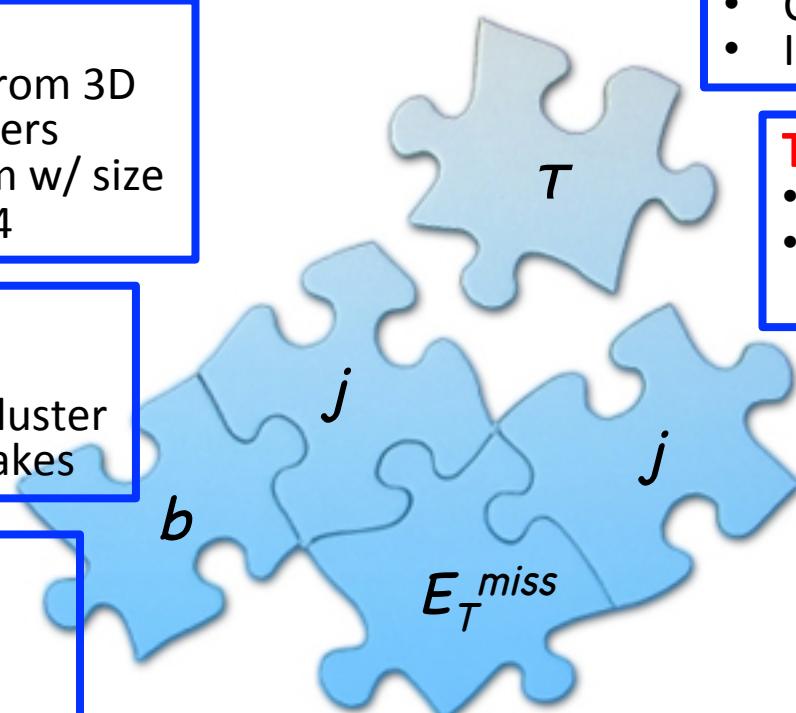
- Displaced tracks or secondary lepton
- SV0: reconstructed secondary vertex
- JetProb: track/jet compatibility with PV

## Muons:

- Combined MS and ID track
- Isolation to suppress fakes

## Taus:

- Double-cone algorithm
- Seeded from EM and HAD calo clusters



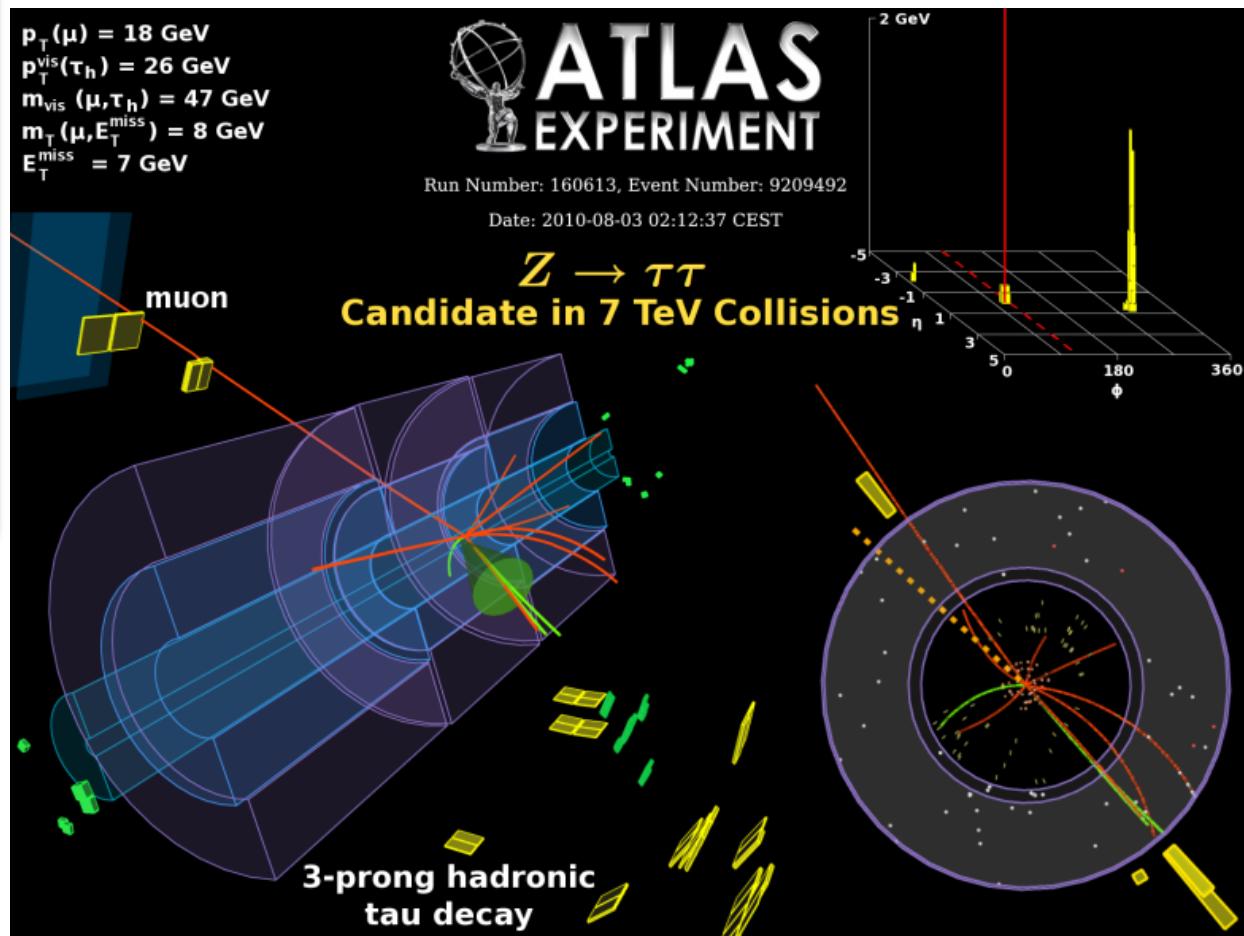
## Missing Transverse Energy ( $E_t^{\text{miss}}$ ):

- Vector sum of calor energy
- Corrected for identified objects

Standard Model → Standard Candle: use expected signals to validate the object reconstruction and refine analysis techniques

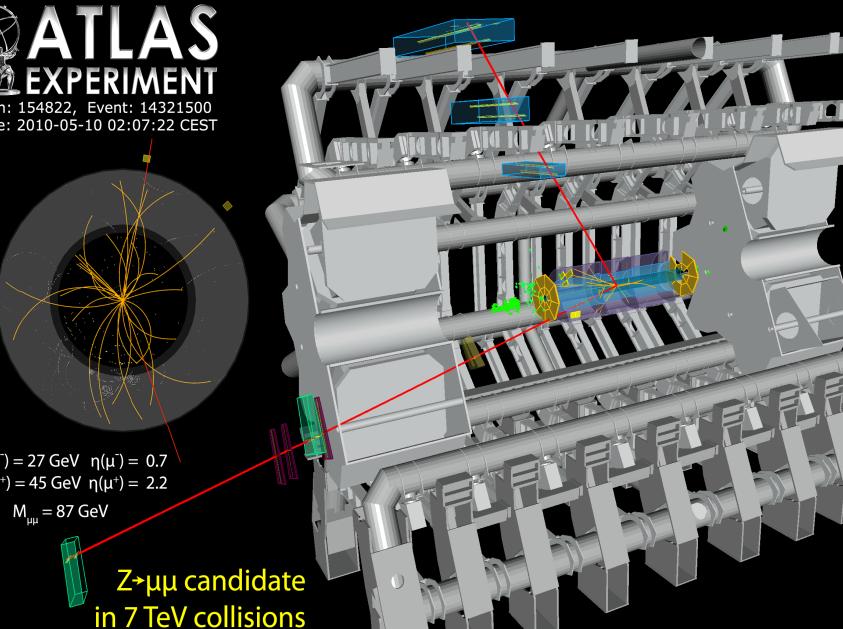
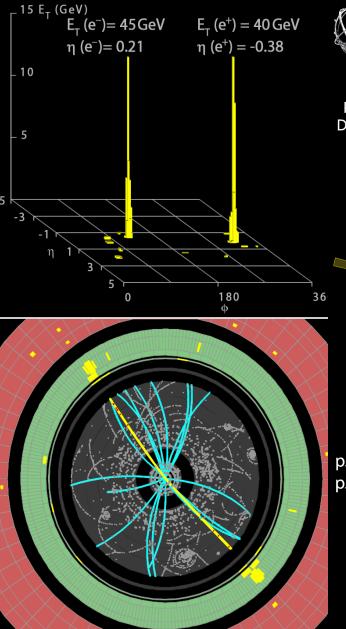
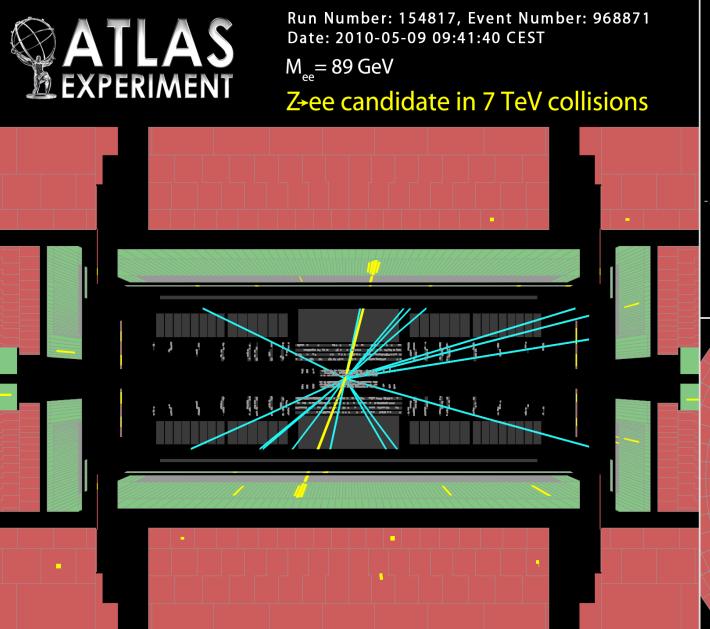
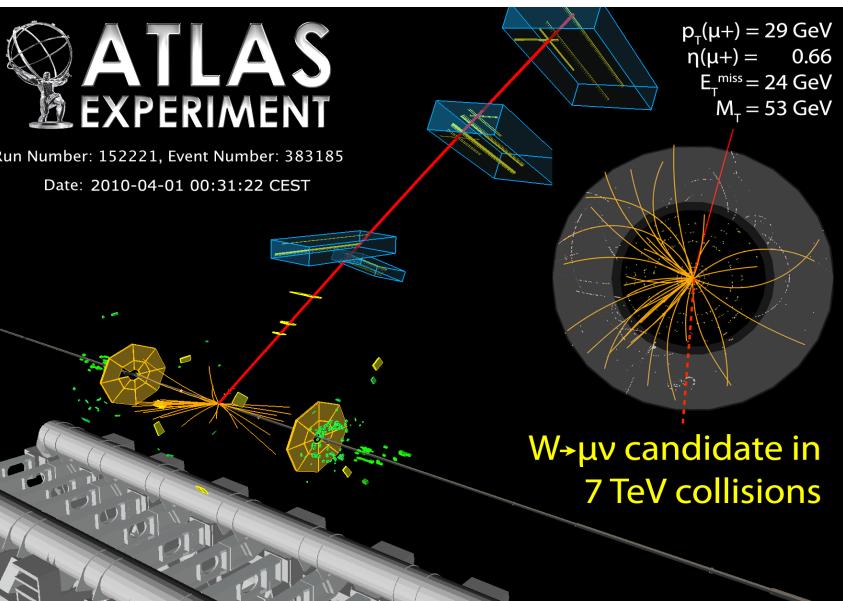
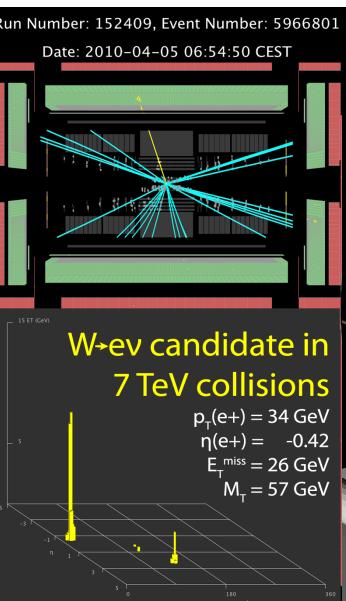
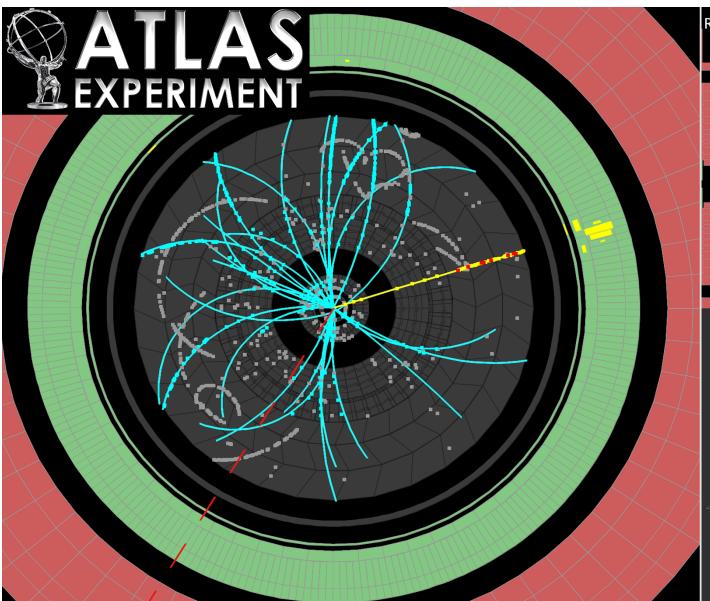


# Weak Bosons





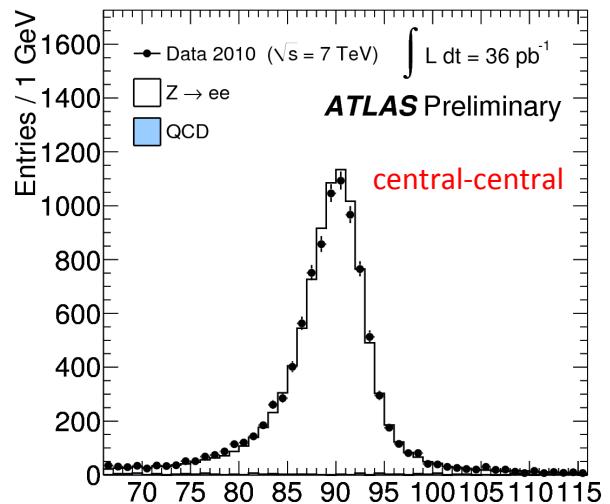
# Weak Boson (W and Z) Events



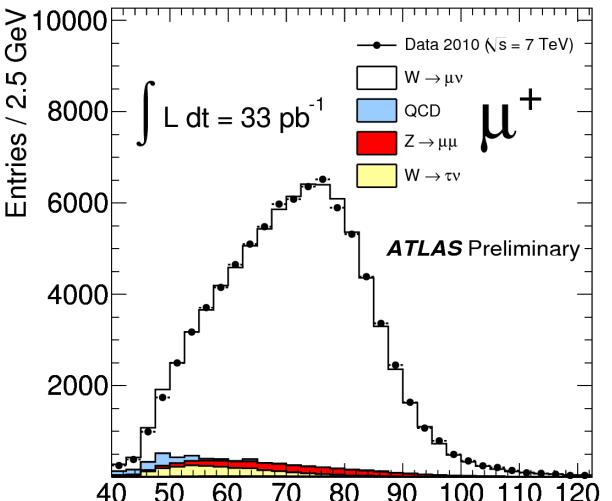


# Weak Boson Signals

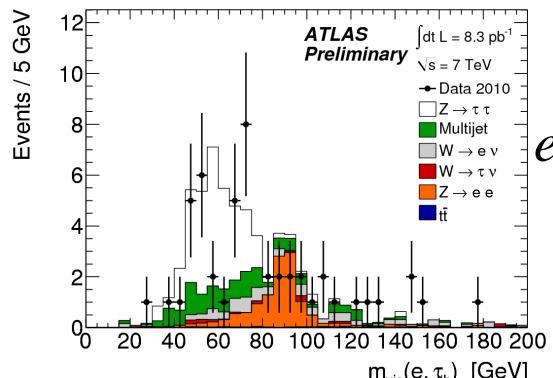
$$Z \rightarrow e^+ e^-$$



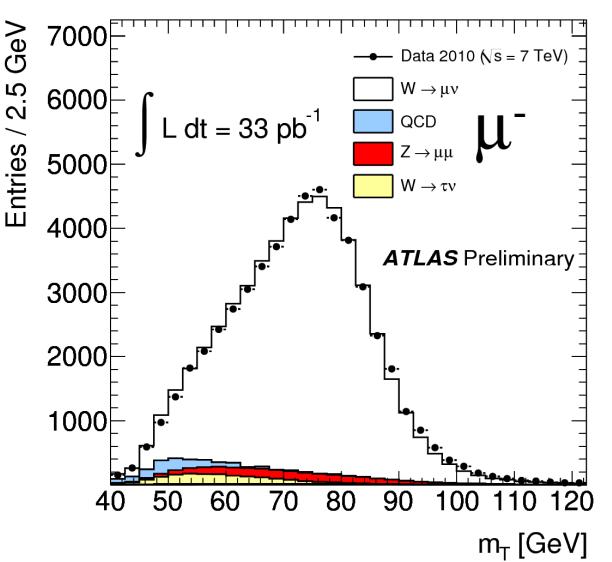
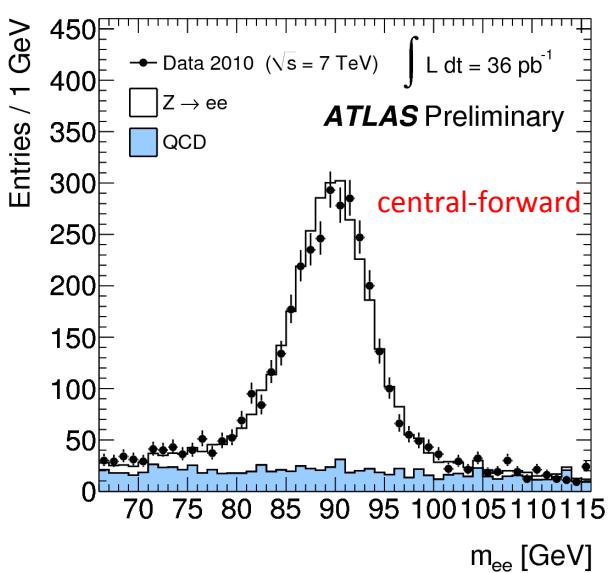
$$W \rightarrow \mu\nu$$



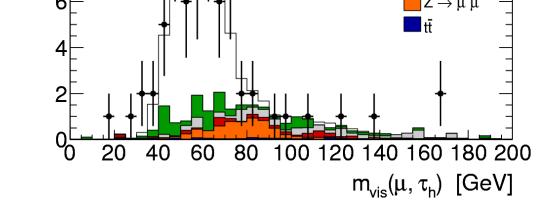
$$Z \rightarrow \tau^+ \tau^-$$



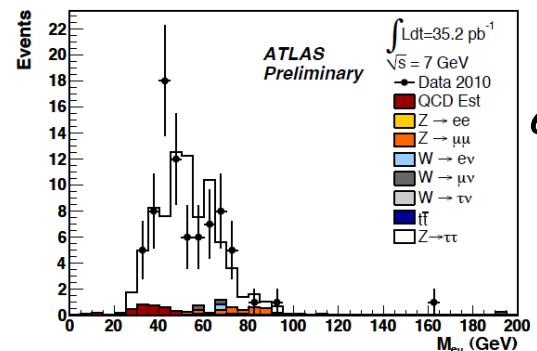
$e + \tau_h$



$\mu + \tau_h$



$e + \mu$

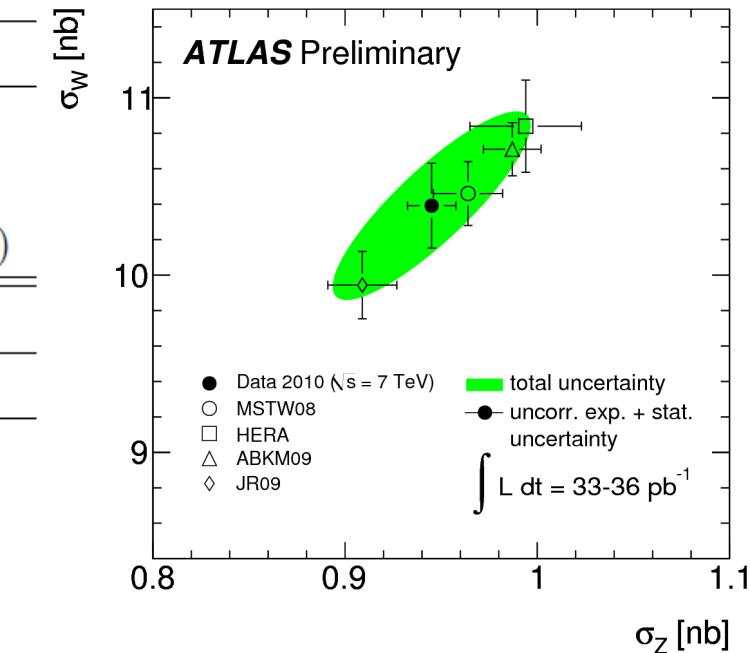
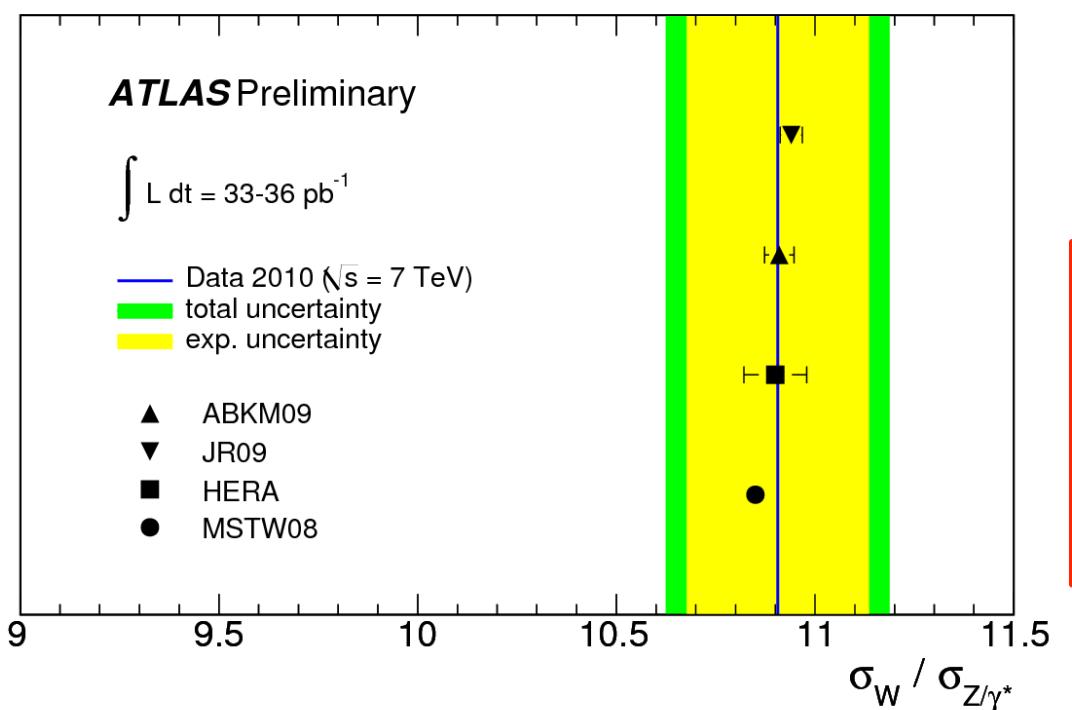




# W and Z Inclusive Cross Sections



	$\sigma_{W^{(\pm)}}^{\text{tot}} \cdot \text{BR}(W \rightarrow \ell\nu) [\text{nb}]$
$W^+$	$6.257 \pm 0.017(\text{sta}) \pm 0.152(\text{sys}) \pm 0.213(\text{lum}) \pm 0.188(\text{acc})$
$W^-$	$4.149 \pm 0.014(\text{sta}) \pm 0.102(\text{sys}) \pm 0.141(\text{lum}) \pm 0.124(\text{acc})$
$W$	$10.391 \pm 0.022(\text{sta}) \pm 0.238(\text{sys}) \pm 0.353(\text{lum}) \pm 0.312(\text{acc})$
	$\sigma_{Z/\gamma^*}^{\text{tot}} \cdot \text{BR}(Z/\gamma^* \rightarrow \ell\ell) [\text{nb}], 66 < m_{ee} < 116 \text{ GeV}$
$Z/\gamma^*$	$0.945 \pm 0.006(\text{sta}) \pm 0.011(\text{sys}) \pm 0.032(\text{lum}) \pm 0.038(\text{acc})$



- NNLO calculations within FEWZ are consistent with the data
- Remarkable success of pQCD and PDF determination

# W Charge Asymmetry

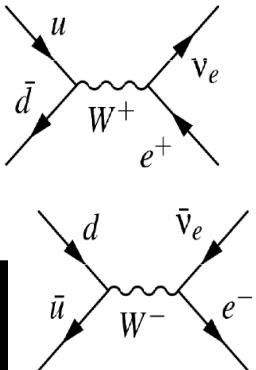


**Sensitive to proton valence quark distribution.**

- More  $W^+$  than  $W^-$  produced at LHC (2u/1d - quark)
- Can be used to constrain PDFs. (Important for  $10^{-3} \leq x \leq 10^{-1}$ )

**Measured in  $\mu$ -channel vs  $\mu$  pseudorapidity:**

$$A_\mu = \frac{\frac{d\sigma_{W\mu+}}{d\eta_\mu} - \frac{d\sigma_{W\mu-}}{d\eta_\mu}}{\frac{d\sigma_{W\mu+}}{d\eta_\mu} + \frac{d\sigma_{W\mu-}}{d\eta_\mu}}$$



**Many experimental uncertainties cancel in Asymmetry**

## Selection

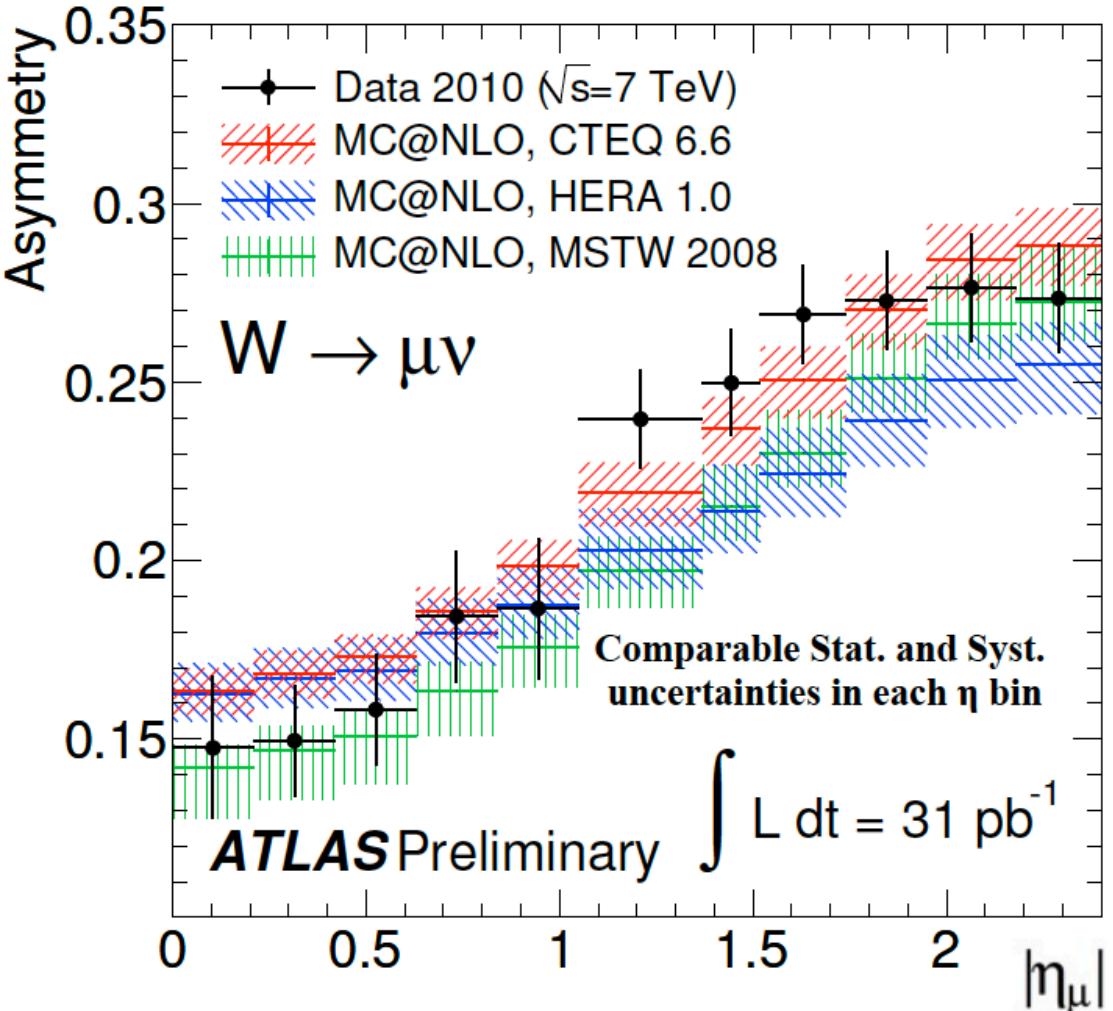
$P_T^\mu > 20 \text{ GeV}$ ,  $E_T^{miss} > 25 \text{ GeV}$ ,  $m_T > 40 \text{ GeV}$   
 $1.30 \times 10^5$  Candidates

## Background Estimation

**7% of candidate events:** 6% leptonic ( $Z \rightarrow \mu\mu(\tau\tau)$ )/ $W \rightarrow \tau\nu/t\bar{t}$ )  
1% QCD jets (data-driven)



# W Charge Asymmetry

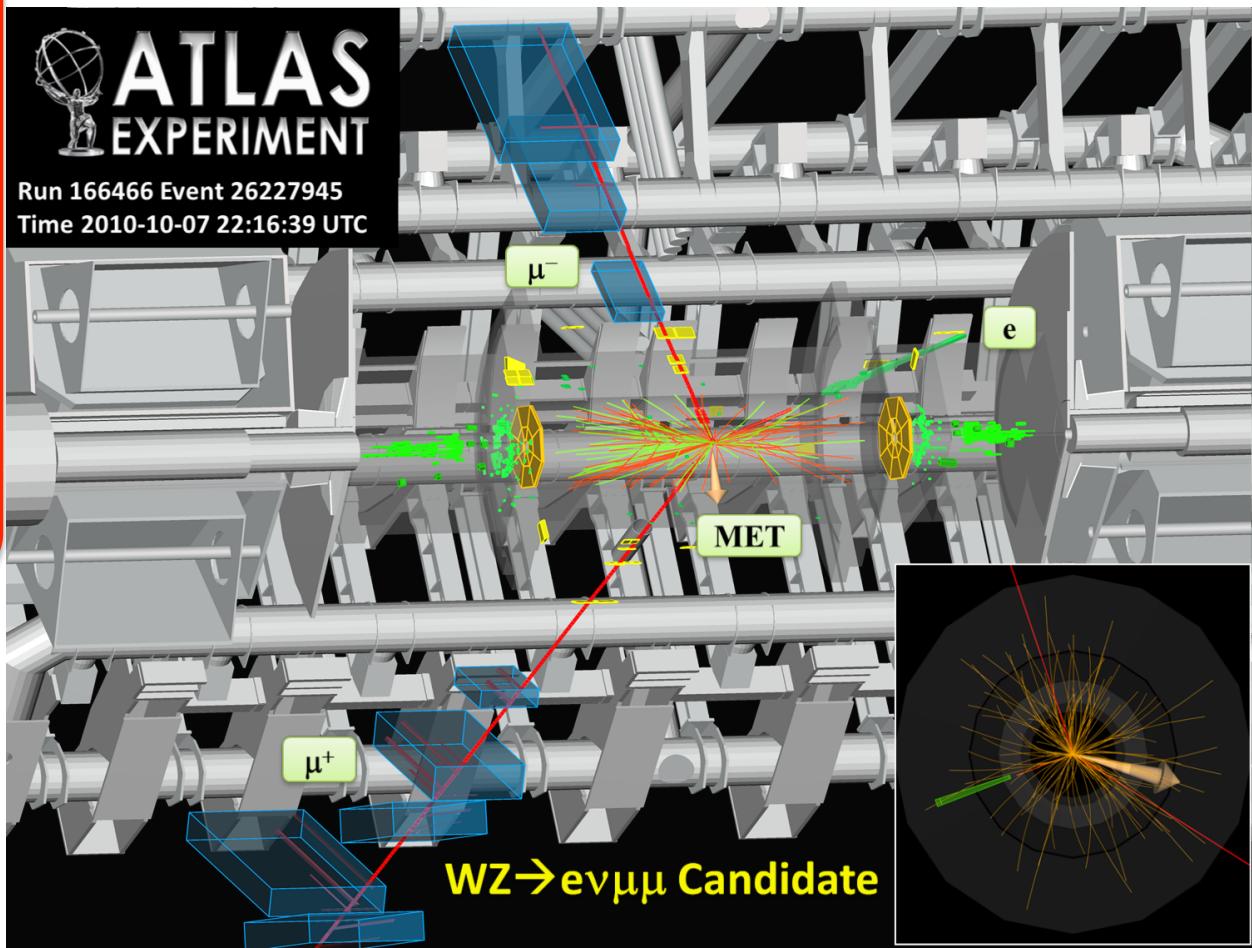


Source	Relative Uncertainty
Trigger	2-7%
$\mu$ - rec	1-7%
Mom. scale	1-2%
Background	1-2%
Systematics limited by Data Statistics in Control Samples	

Current Experimental Uncertainties Already Comparable to those of Global Fits.



# Diboson



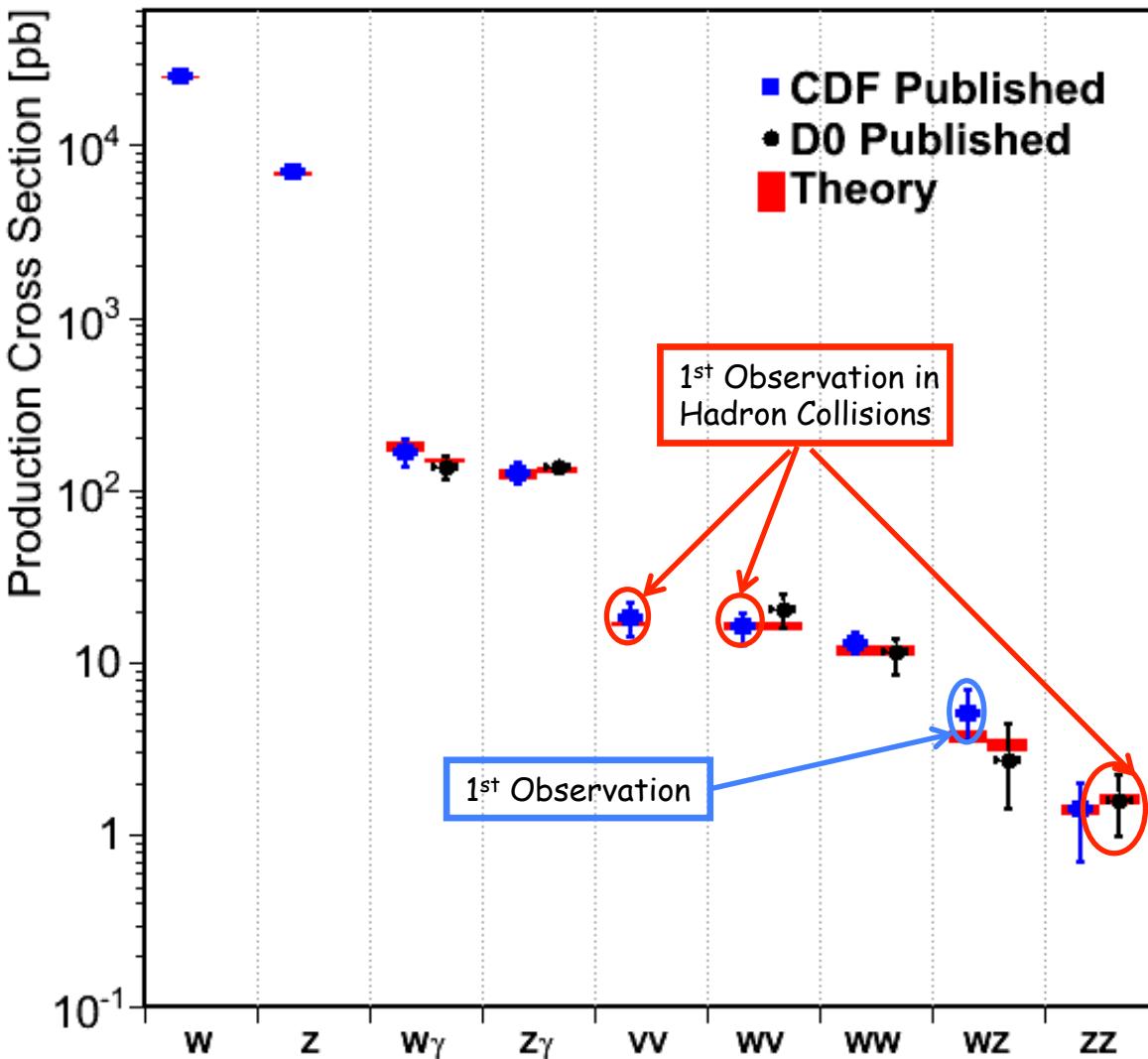


# "Best Hits from the Tevatron RunII"



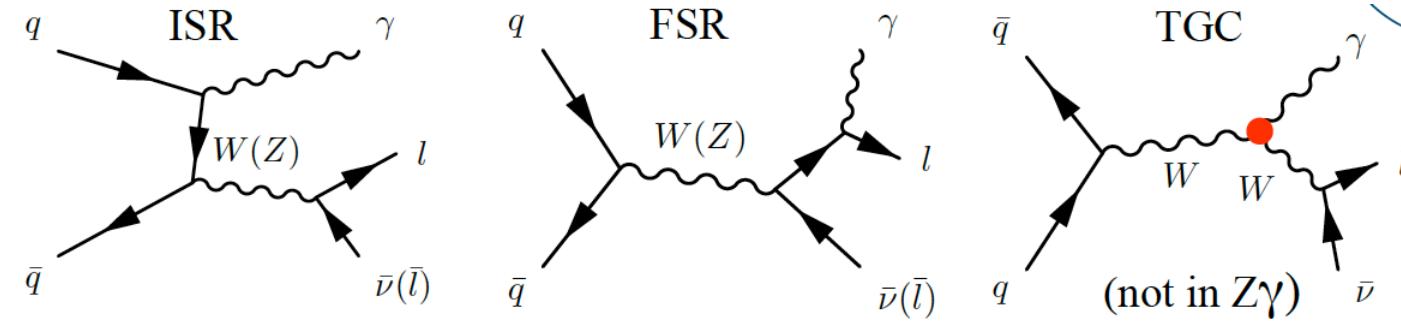
Run II

Track 1: Diboson physics





# $W\gamma$ and $Z\gamma$ cross sections



## Signature:

- W/Z selection
- Isolated photon w/

$$E_T^\gamma > 15 \text{ GeV}$$

$$E_T^{\text{iso}} < 5 \text{ GeV}$$

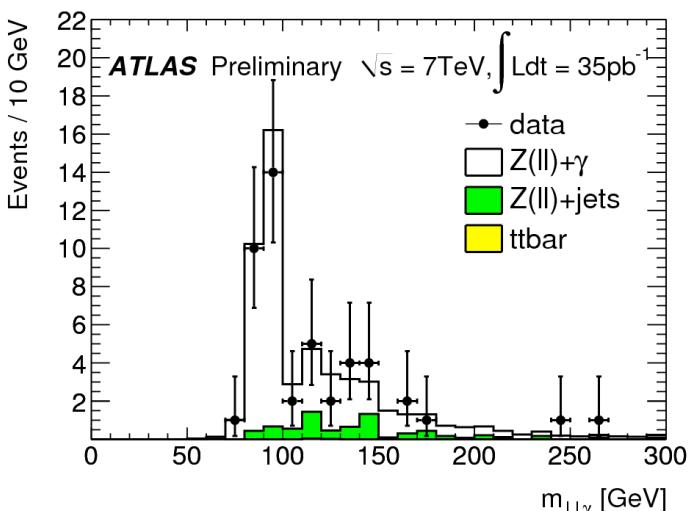
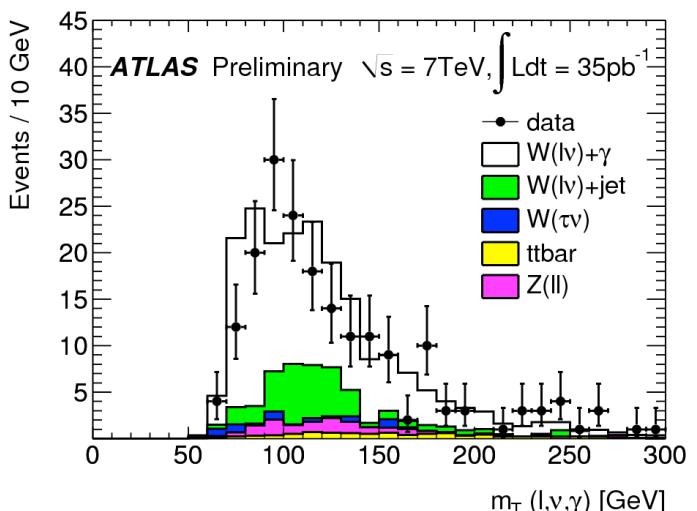
$$\Delta R(\ell, \gamma) > 0.7$$

Dominant background:

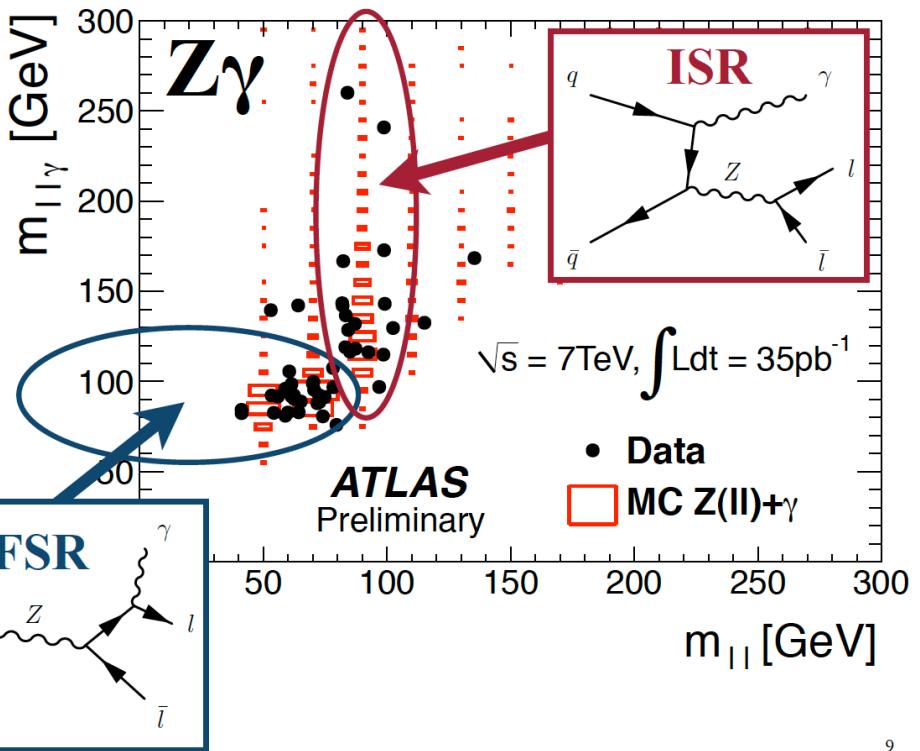
- W/Z + jets

$W\gamma$	e-channel	$\mu$ -channel
Event Yield	<b>95</b>	<b>97</b>
W+Jets Bkg (Data)	$16.9 \pm 6.4 \pm 7.3$	$16.8 \pm 4.7 \pm 7.3$
EW Bkg (MC)	$10.1 \pm 0.8 \pm 1.1$	$12.4 \pm 0.9 \pm 1.4$

$Z\gamma$	e-channel	$\mu$ -channel
Event Yield	<b>25</b>	<b>23</b>
Background (MC)	$3.8 \pm 3.8$	$3.4 \pm 3.4$



# W $\gamma$ and Z $\gamma$ cross sections



Systematics dominated by uncertainties on the photon reconstruction and identification efficiency, photon isolation cut efficiency

Cross section reported for:

$$E_T^\gamma > 10 \text{ GeV}$$

$$f_{iso}^\gamma < 0.5$$

$$\Delta R(\ell, \gamma) > 0.5$$

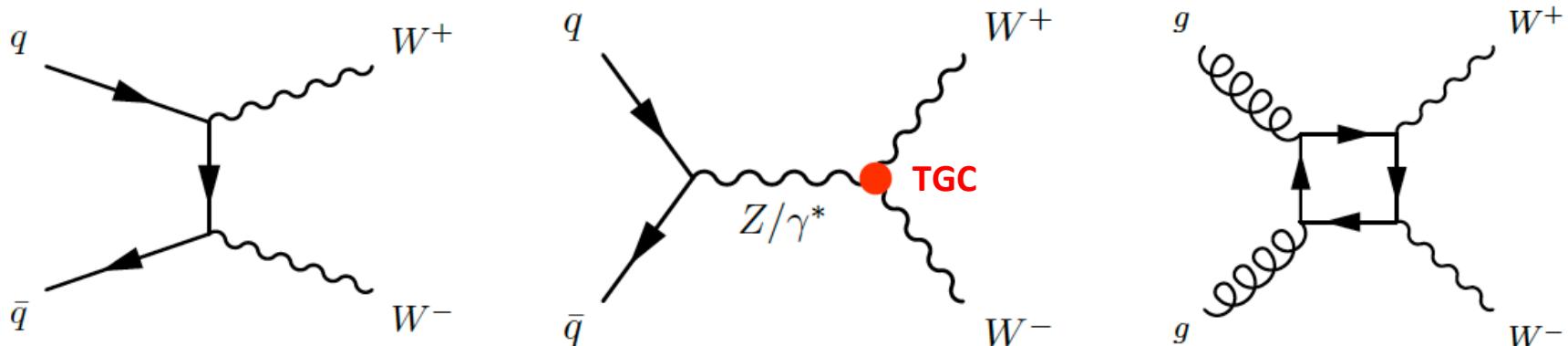
9

<b>W+<math>\gamma</math>+X</b>	<b>Measured cross section (pb)</b>
e-channel	$73.9 \pm 10.5 \text{ (stat)} \pm 15.9 \text{ (sys)} \pm 8.1 \text{ (lumi)}$
$\mu$ -channel	$58.6 \pm 8.2 \text{ (stat)} \pm 11.7 \text{ (sys)} \pm 6.4 \text{ (lumi)}$
SM NLO Prediction: $69.0 \pm 4.6 \text{ (sys)}$	

<b>Z+<math>\gamma</math>+X</b>	<b>Measured cross section (pb)</b>
e-channel	$16.4 \pm 4.5 \text{ (stat)} \pm 4.3 \text{ (sys)} \pm 1.8 \text{ (lumi)}$
$\mu$ -channel	$10.6 \pm 2.6 \text{ (stat)} \pm 2.5 \text{ (sys)} \pm 1.2 \text{ (lumi)}$
SM NLO Prediction: $13.8 \pm 0.9 \text{ (sys)}$	

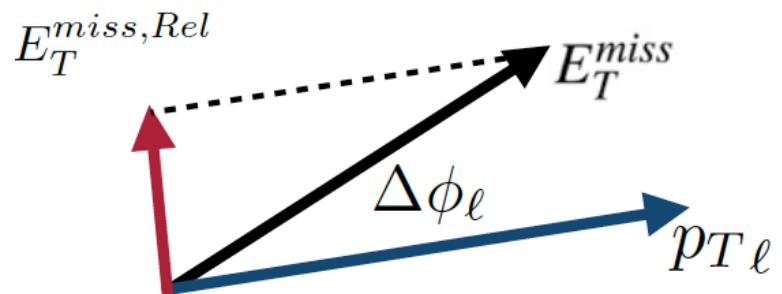
First W $\gamma$  and Z $\gamma$  cross section measurements at 7 TeV

# WW Cross Section



## Signature:

- Fully-leptonic W decay
- 2 Opposite-sign leptons ( $e, \mu$ )
- Large Missing Energy



## Dominant backgrounds:

- Drell-Yan:** (lepton pair + ‘fake’ MeT)
- **Require Large Relative MeT**
  - **Reject events consistent w/Z mass**

## Other Diboson:

- (WZ, ZZ, W\gamma)
- **remove events w/ > 2 leptons.**

## W+Jets:

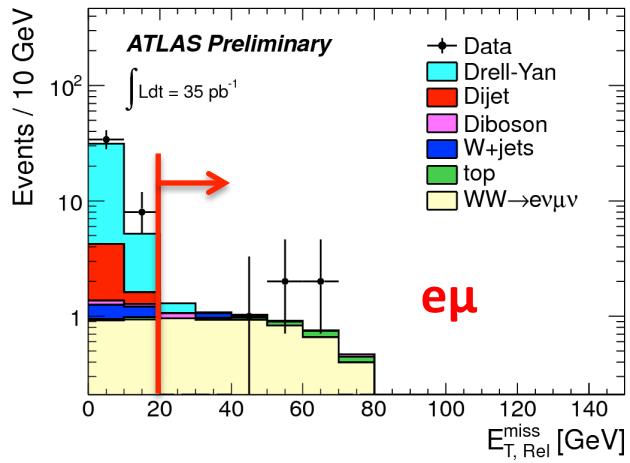
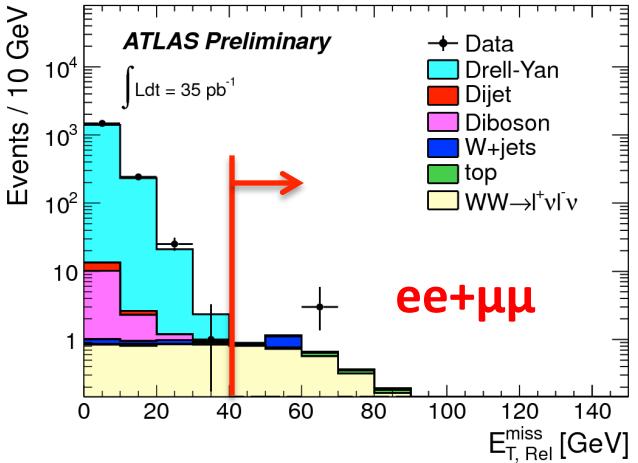
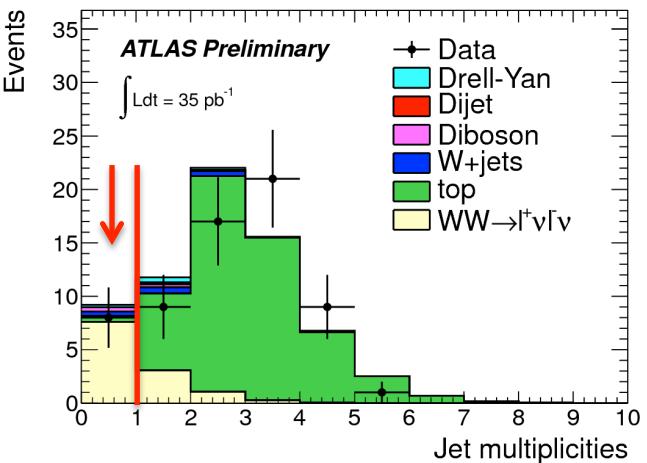
- (lepton w/MeT + ‘fake’ lepton)
- **Isolation / lepton Identification**

## Top:

- (WW produced w/2 b-jets)
- **Jet Veto**



# WW Cross Section



## Backgrounds

## Events

Drell Yan (MC)	$0.24 \pm 0.15 \pm 0.17$
Top (MC)	$0.55 \pm 0.12 \pm 0.30$
W+Jets (Data)	$0.54 \pm 0.32 \pm 0.21$
Other Diboson (MC)	$0.39 \pm 0.04 \pm 0.06$
Total Background	$1.72 \pm 0.37 \pm 0.45$

Observed Events

8

1 ee / 2  $\mu\mu$  / 5 e $\mu$

Signal significance:  $3.0 \sigma$

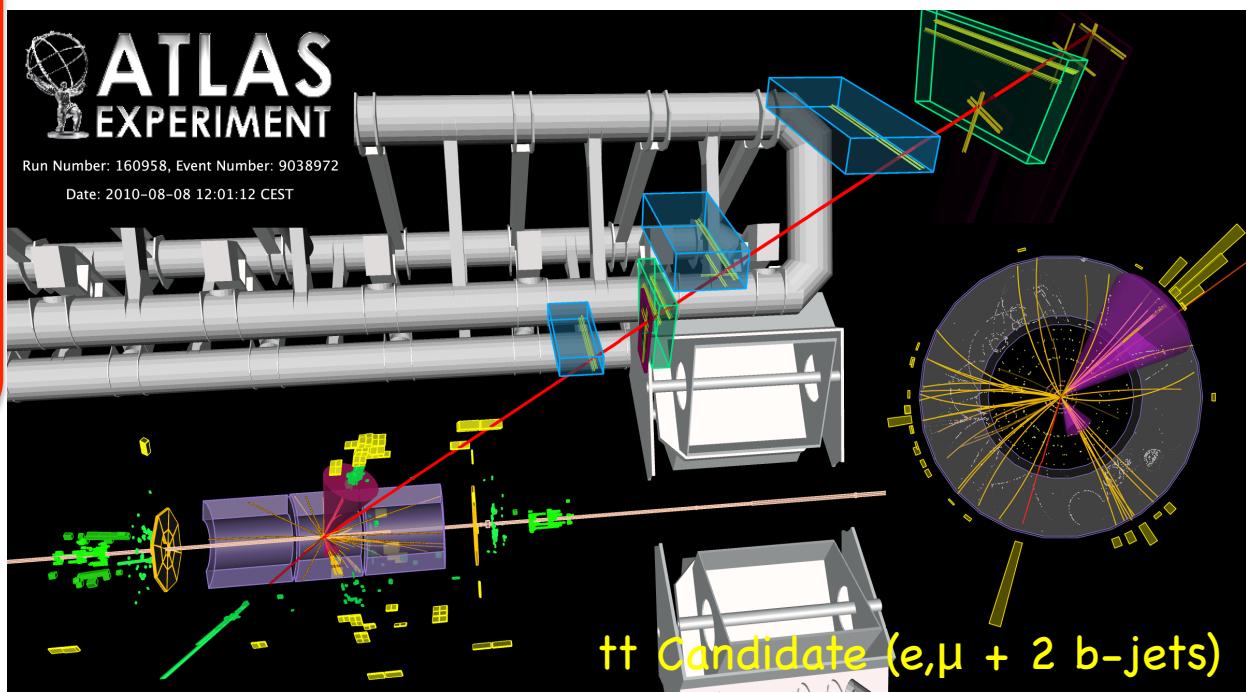
$$\sigma_{WW} = 40^{+20}_{-16}(\text{stat}) \pm 7(\text{syst}) \text{ pb.}$$

NLO Prediction:  $46 \pm 3 \text{ pb}$

(MCFM with MSTW2008 (including gg))



# Top Quark



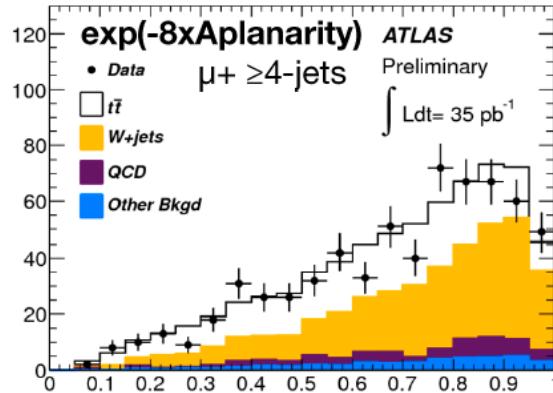
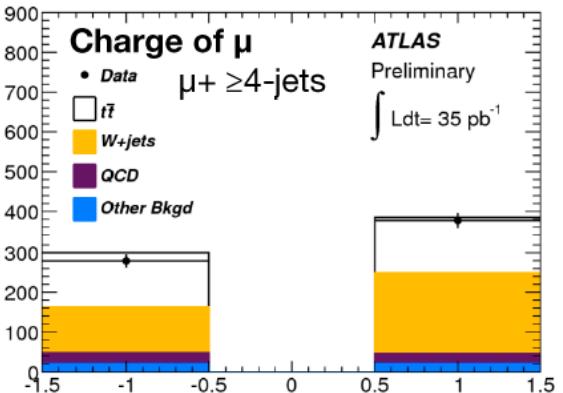
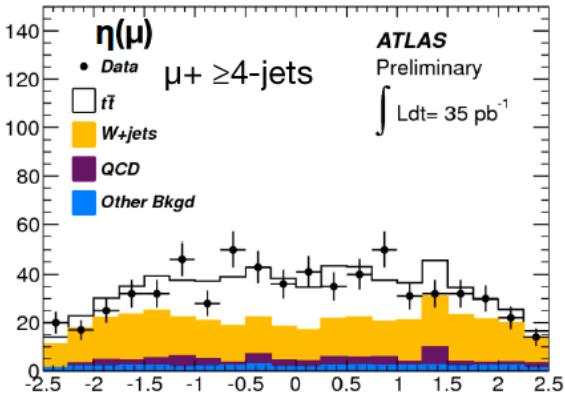


# $\sigma_{\text{tt}}$ Single lepton (no b-tagging)

ATLAS-CONF-2011-023

## ► Analysis strategy

- Projective likelihood based on uncorrelated discriminating variables
- Three variables chosen:



- Binned maximum likelihood to 4 channels (3-jets,  $\geq 4$ -jets; e,  $\mu$ )

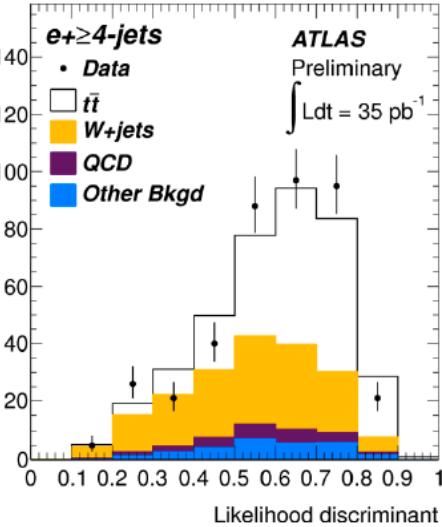
Syst. source	Rel. unc. %
Jet en. scale & Reconstruction	-6.1 / +5.7
ISR/FSR	-2.1 / +6.1
QCD norm.	3.9
QCD shape	3.4
Parton shower & hadronisation	3.3
Total syst.	-10.2 / +11.6

## ► Independent of b-tagging

- avoids related systematic uncertainty at the price of a worse S/B ratio
- Relative uncertainty ~15%

$$\sigma_{\text{tt}} = 171 \pm 17(\text{stat})^{+20}_{-17}(\text{syst}) \pm 6(\text{lumi}) \text{ pb}$$

- cross-checked by cut-and-count and 1d  $\chi^2$  and likelihood fits





# $\sigma_{\text{tt}}$ Single lepton with b-tags

## ► Multivariate method

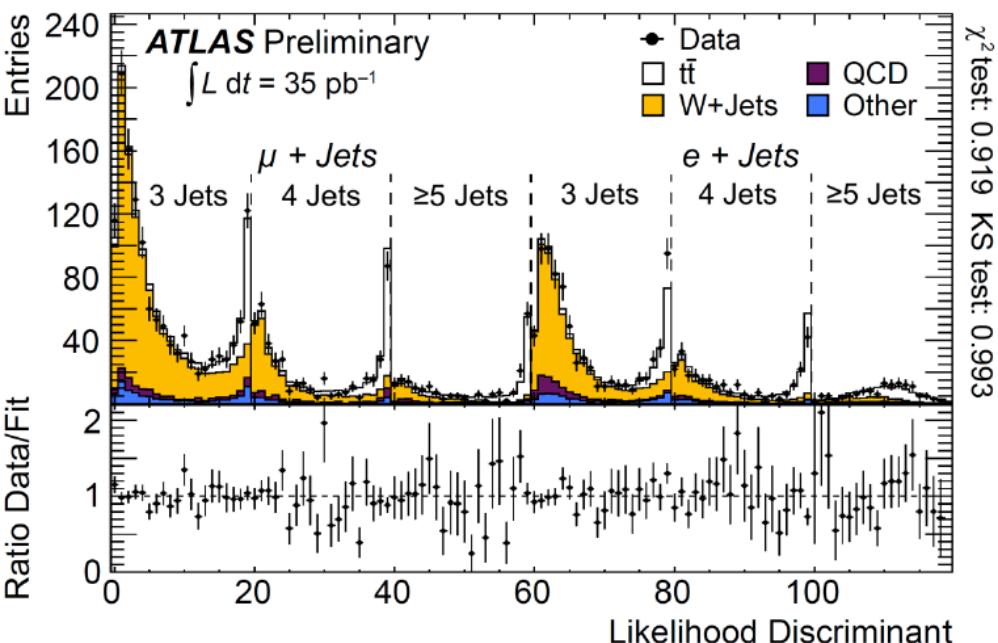
- split up in six channels (3,4, $\geq 5$  jets, e/ $\mu$ )

## ► Input variables

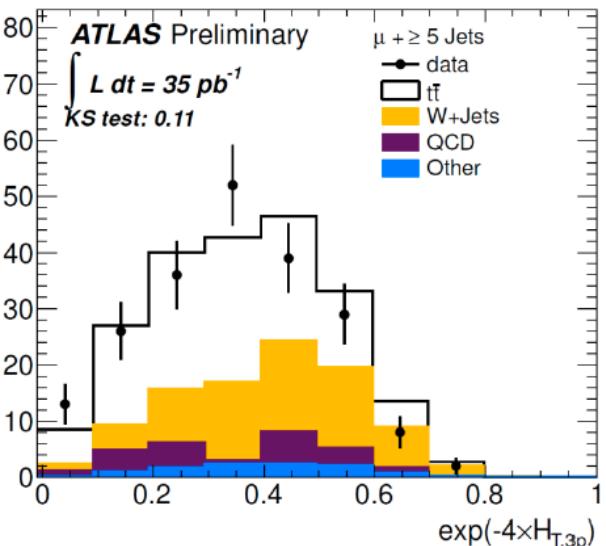
- lepton  $\eta$ , aplanarity,  $H_{T,3p}$ , b-tag weight

## ► Profile likelihood fit extracts

- 16 norm. parameters, including  $\sigma_{\text{tt}}$



ATLAS-CONF-2011-035



## ► Fit is set up with

- 17 nuisance parameters
- constrained from data

## ► Main systematics

- W+jets HF content (7%)
- Tagger calibration (7%)

uncert.  
~13%

$$\sigma_{\text{tt}} = 186 \pm 10(\text{stat})^{+21}_{-20}(\text{syst}) \pm 6(\text{lumi}) \text{ pb}$$

## ► Cross-check analysis

- Cut-and-count, fit to  $m(jjj)$



# $\sigma_{\text{tt}}$ Dilepton

## ► Cut-based method

- require 2 OS hard leptons ( $e, \mu$ ), 20 GeV
- two energetic jets, 20 GeV
- **Z+jets is dominating background**
  - ee/ $\mu\mu$ :  $E_T^{\text{miss}} > 40$  GeV and  $|m_{\parallel} - m_Z| > 10$  GeV
  - $e\mu$ :  $H_T > 130$  GeV

## ► MC-assisted data-driven estimation of remaining Z+jets background

$$N_{Z/\gamma^*+\text{jets}} = \frac{\text{MC}_{Z/\gamma^*+\text{jets}}(\text{SR})}{\text{MC}_{Z/\gamma^*+\text{jets}}(\text{CR})} \times (\text{Data}(\text{CR}) - \text{MC}_{\text{other}}(\text{CR}))$$

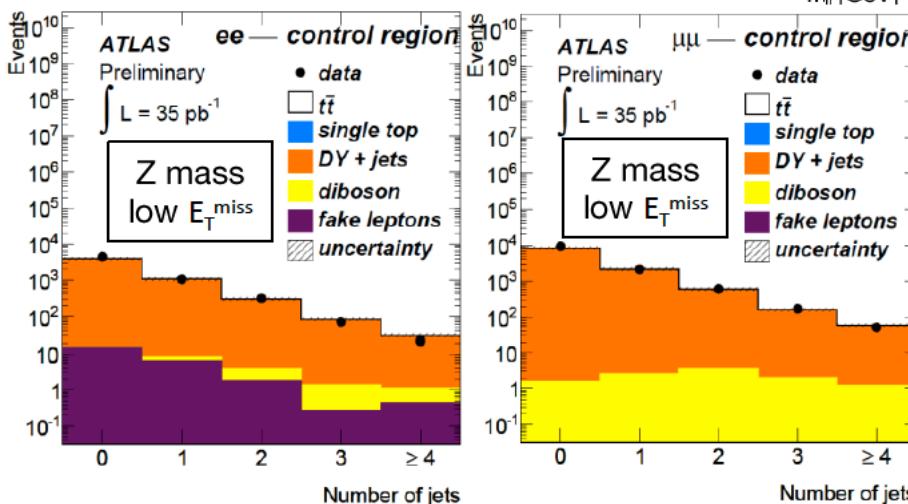
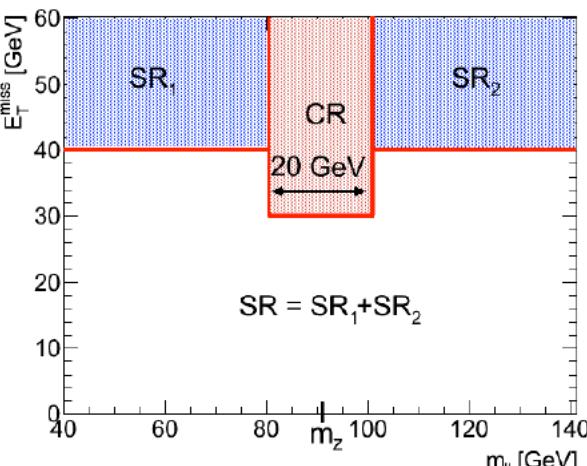
- Reduced uncertainty from  $\sim 100\%$  to  $< 50\%$

## ► Main systematics

- Jet energy scale (5%)
- Parton shower model (5%)
- Fakes (4%)

Can also simultaneously extract

- $\sigma_Z$ , lumi uncertainty cancels in ratio
- $\sigma_{\text{tt}}$ ,  $\sigma_{\text{WW}}$ ,  $\sigma_{Z \rightarrow \pi\pi}$  from fit  $E_T^{\text{miss}}$  vs  $N_{\text{jets}}$
- b-tagging efficiency





# $\sigma_{tt}$ Dilepton

## ► Cross-section extraction

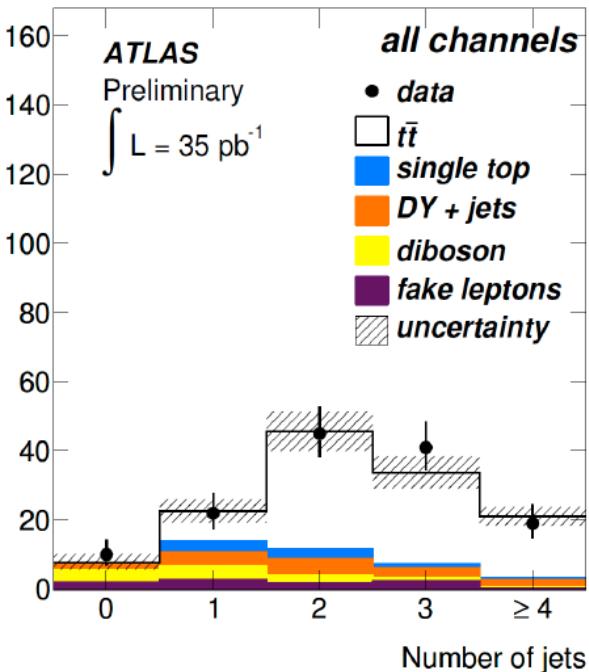
### – Profile likelihood method to combine channels

$$L_H(\sigma_{tt}, \mathcal{L}, \alpha_j) = \text{Gaus}(\mathcal{L}_0 | \mathcal{L}, \sigma_{\mathcal{L}}) \prod_{i \in \{ee, \mu\mu, e\mu\}} \text{Pois}(N_i^{\text{obs}} | N_{i,\text{tot}}^{\text{exp}}(\alpha_j)) \prod_{j \in \text{syst}} \text{Gaus}(0 | \alpha_j, 1)$$

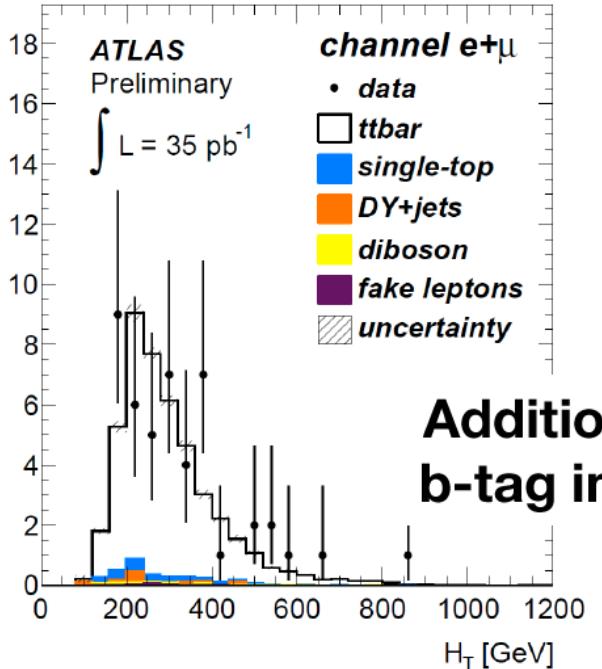
$$\sigma_{tt} = 173 \pm 22(\text{stat})^{+18}_{-16} (\text{syst})^{+8}_{-7} (\text{lumi}) \text{ pb}$$

### – Events in SR are compatible with top quarks

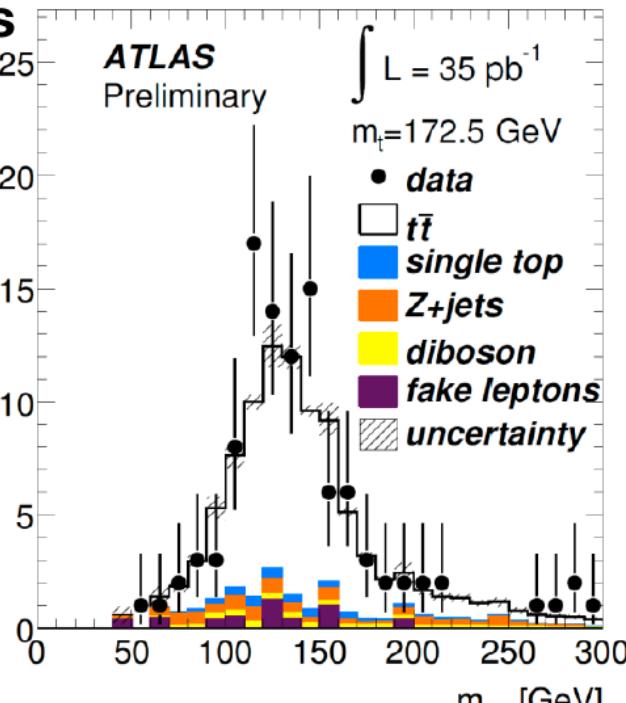
105 events selected,  $101 \pm 9$  expected  
Data well modeled by MC+DD methods



$H_T$ : sum of lepton and jet momenta  
Distribution after requiring 1 b-tag



Stransverse mass: generalization of  $m_T$  concept with two neutrinos



**Additionally requiring  
b-tag improves S/B**



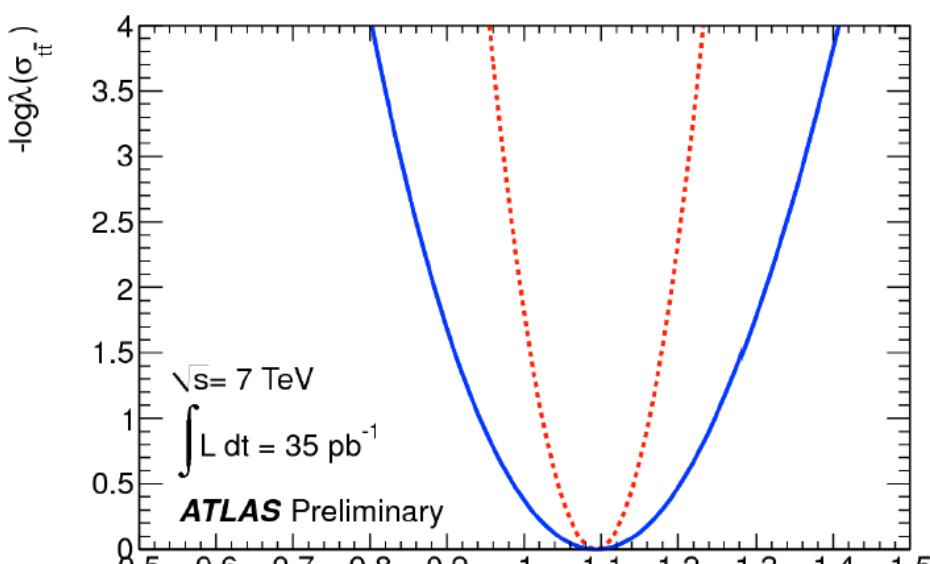
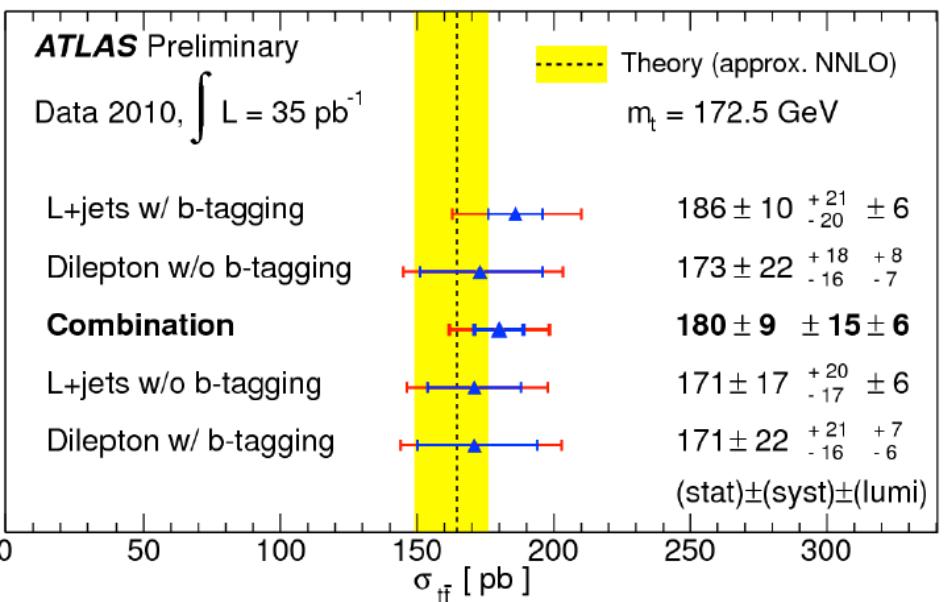
# $\sigma_{\text{tt}}$ Combination

## ► Combine dilepton and single lepton channels

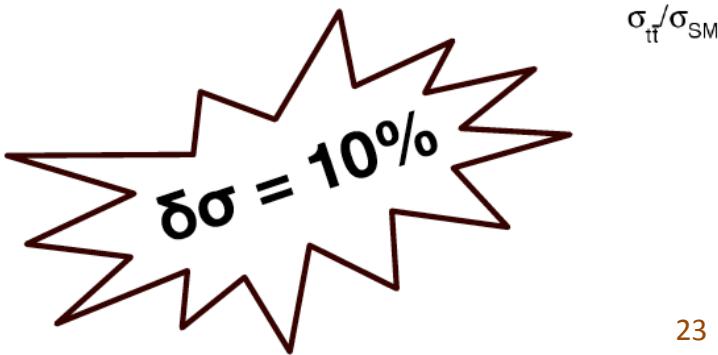
- extend 3 channel to 5 channels

- choose most precise: L+jets with b-tag, dilepton w/o b-tag

ATLAS-CONF-2011-040



- Statistical uncertainty ~4%
- Systematic uncertainty ~8%
- Luminosity uncertainty ~3%
- Agrees with QCD prediction

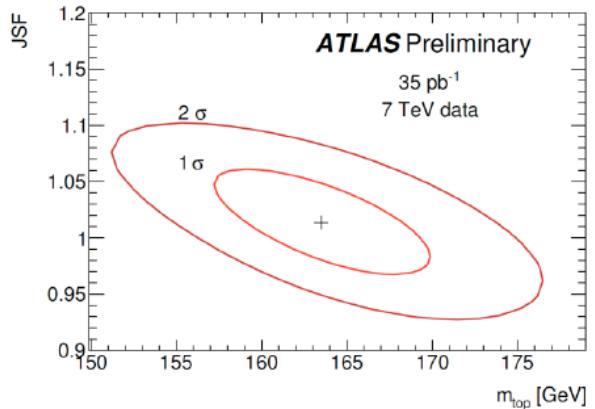
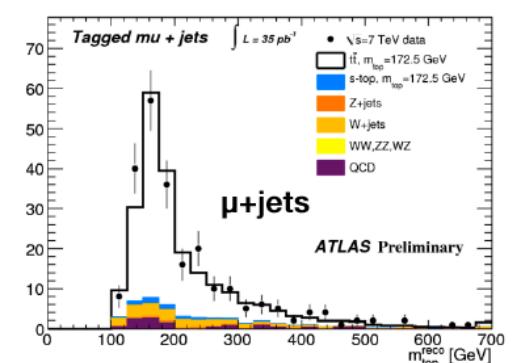
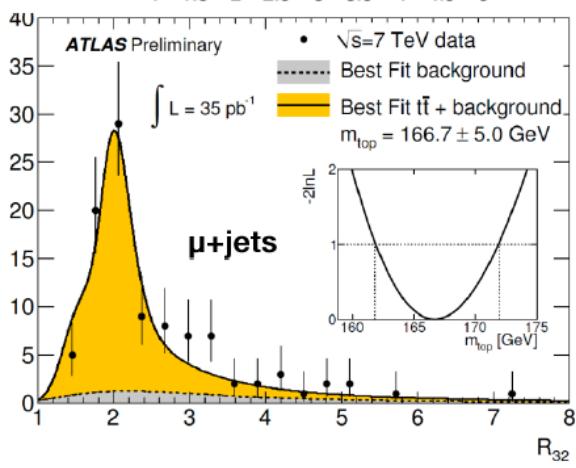
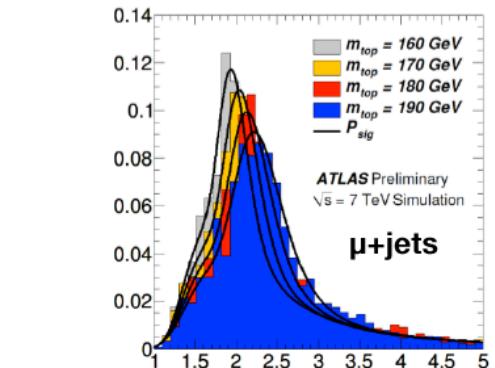




# Top Quark Mass (Template Method)



ATLAS-CONF-2011-033



## ► First ATLAS measurement

- Main aim: reduce JES uncertainty systematic

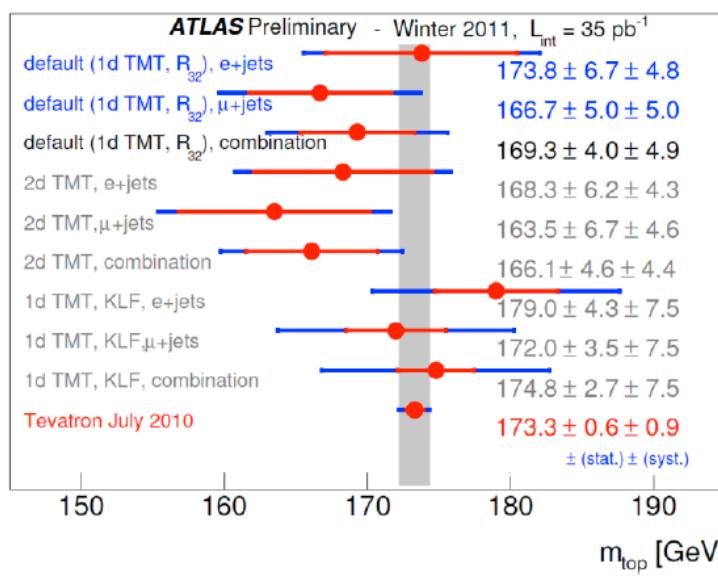
## ► Template in $R_{32} = m_{jjb}(t) / m_{jj}(W)$

$$m_{top} = 169.3 \pm 4.0(\text{stat}) \pm 4.9(\text{syst}) \text{ GeV}$$

## ► Systematics (b-)JES , ISR/FSR

## ► Cross-checked by

- kinematic fit templates
- 2d templates with Jet Scaling Factor



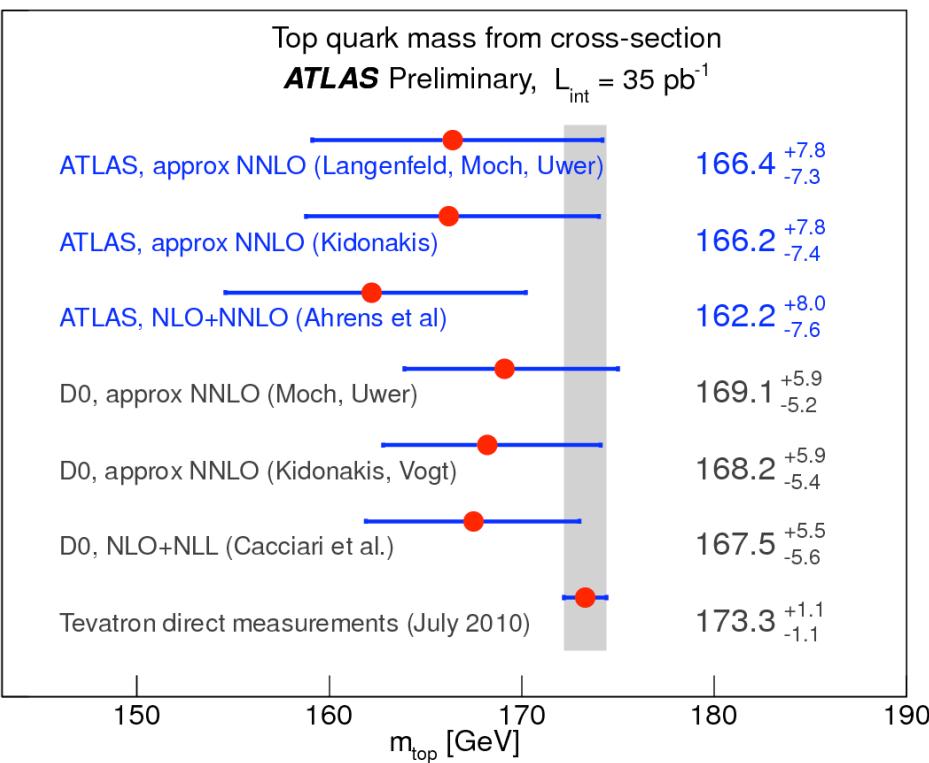
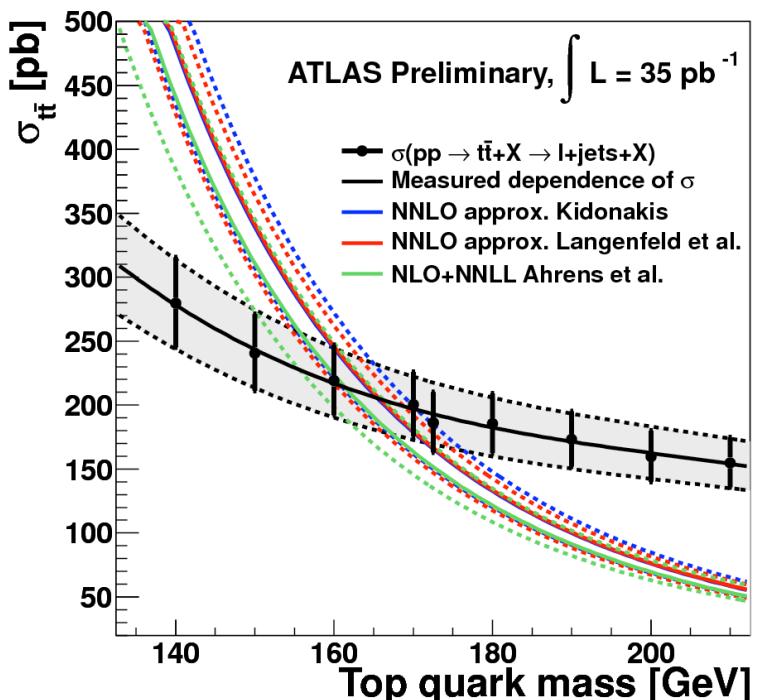
# Top Quark Mass from $\sigma_{tt}$



New  
Since  
Moriond!

Compare measured  $\sigma_{tt}$  (lepton + jets) with fully-inclusive pQCD calculation at high order

- Top quark mass parameter unambiguously defined as pole mass ( $m_{top}^{pole}$ )



Complementary to direct top mass measurements that rely on modeling the details of the kinematic mass reconstruction



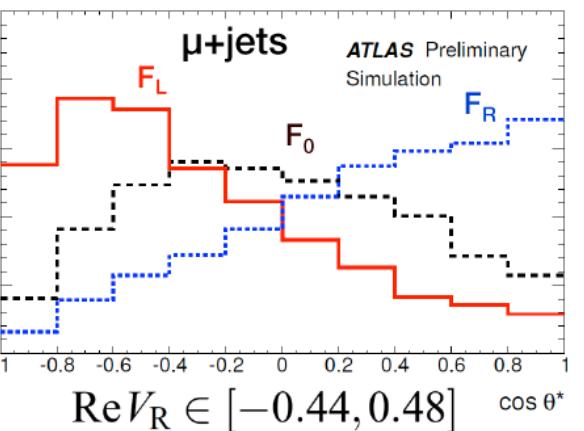
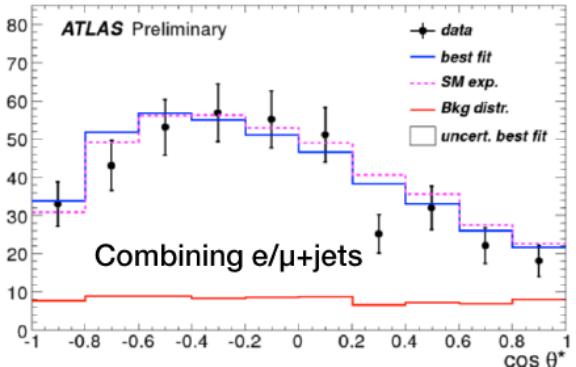
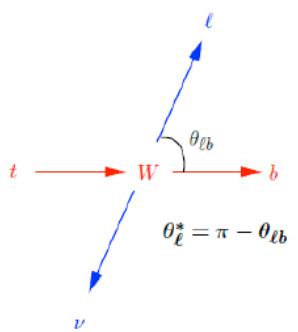
# W Helicity in Top Quark decays



ATLAS-CONF-2011-037

## ► Standard Model predicts helicity fractions of W from top

- $F_L = 0.301$ ,  $F_0 = 0.698$ ,  $F_R = 4.1 \cdot 10^{-4}$
- Wtb structure probed by verifying this; set limits on new physics
- Can extract directly from  $\cos \theta^*$  or unfold and calculate asymmetry
- Use e+jets and  $\mu$ +jets channels



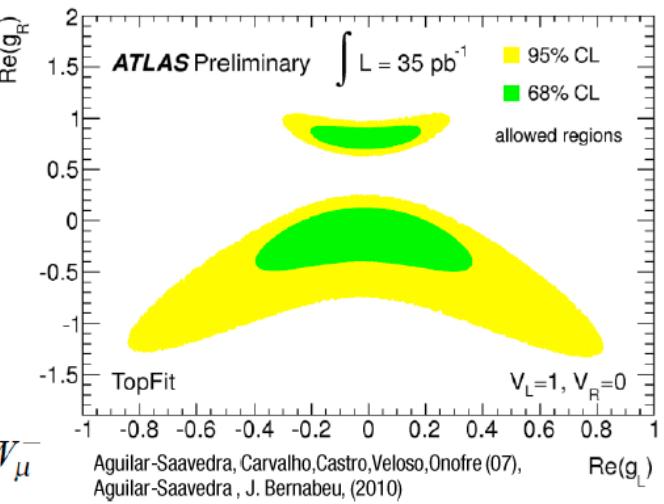
	Template method	Asymmetry method
$F_L$	$0.41 \pm 0.12$	$0.36 \pm 0.10$
$F_0$	$0.59 \pm 0.12$	$0.65 \pm 0.15$
$F_R$	Fixed 0	$-0.01 \pm 0.07$

$$\text{Re } V_R \in [-0.44, 0.48]$$

$$\text{Re } g_L \in [-0.24, 0.21]$$

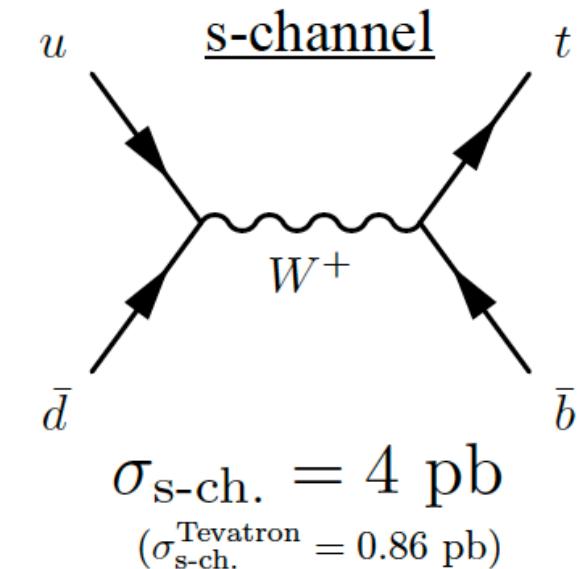
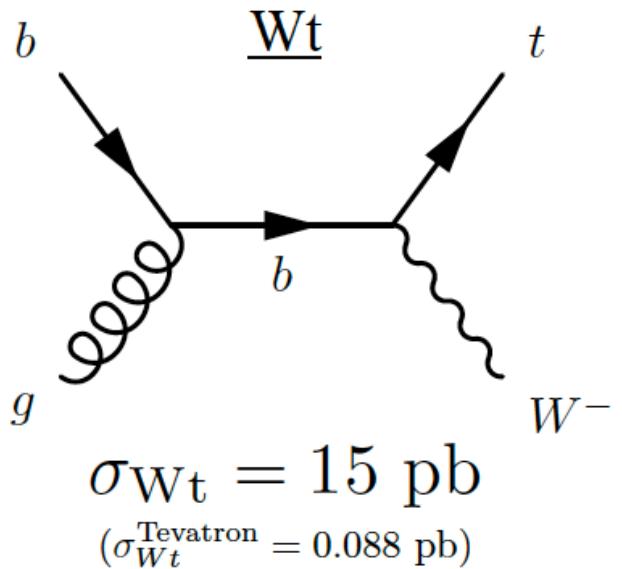
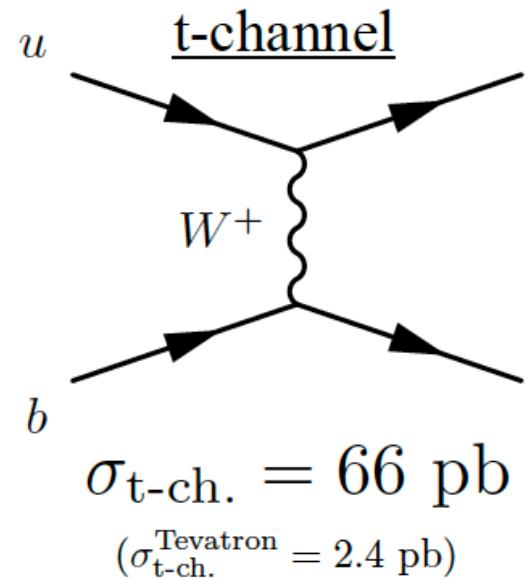
$$\text{Re } g_R \in [-0.49, 0.15]$$

$$\mathcal{L}_{Wtb} = -\frac{g}{\sqrt{2}} \bar{b} \gamma^\mu (V_L P_L + V_R P_R) t W_\mu^- - \frac{g}{\sqrt{2}} \bar{b} \frac{i \sigma^{\mu\nu} q_v}{M_W} (g_L P_L + g_R P_R) t W_\mu^-$$



Aguilar-Saavedra, Carvalho, Castro, Veloso, Onofre (07),  
Aguilar-Saavedra, J. Bernabeu, (2010)

# Single Top



## Motivation:

- Single Top is a direct probe of CKM element  $V_{tb}$
- 3 modes w/distinct signatures
- Sensitive to many models of new physics.

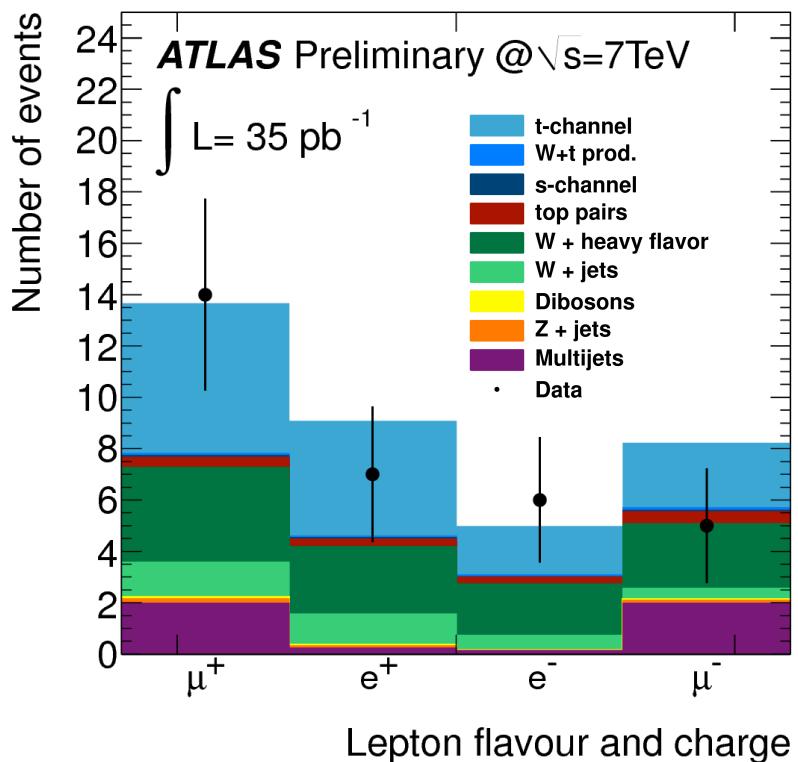
## Present Searches in the t- and Wt channel

# Single Top: t-channel



## Signature:

- One lepton ( $e/\mu$ )  $E_T^l > 20$  GeV
- $E_T^{miss} > 25$  GeV
- $m_T^W > 60$  GeV –  $E_T^{miss}$
- 2 - jets (one b-jet)
- $130 < m_{Top} < 210$  GeV
- Light-jet eta  $|\eta_{(lf-jet)}| > 2.5$



	$\ell^+$ channel	$\ell^-$ channel
<b>t-channel expectation</b>	$10.3 \pm 1.8$	$4.4 \pm 0.8$
<b>Bkg (Data/MC)</b>	$12.4 \pm 3.3$	$8.8 \pm 1.8$
<b>Observed</b>	21	11

## Results

- Signal Significance of  $1.6\sigma$
- Observed Limit:  $\sigma_t < 162 \text{ pb}$   
(95 % Confidence level)
- Expected Limit:  $\sigma_t < 182 \text{ pb}$

**Limiting systematics:** Jet Energy Scale,  
b-tagging efficiency, Background Modeling

## Results

- Cross checked with likelihood method.
- Observed excess consistent w/SM prediction

# Single Top: Wt



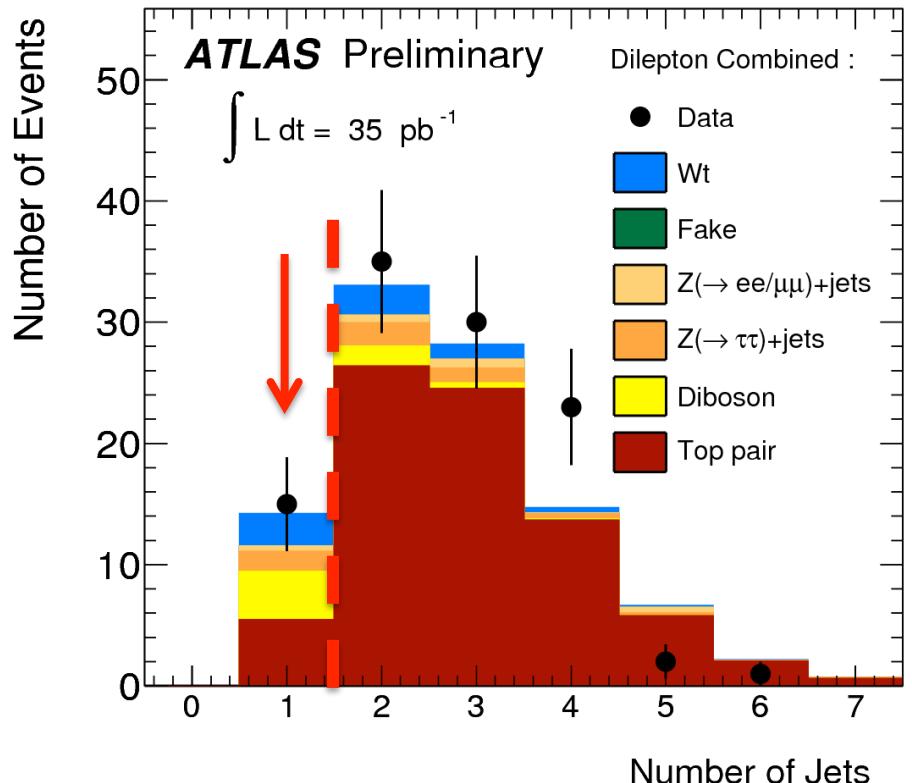
**Two W Bosons in Final State**

## Single Lepton Channel

Similar to t-channel analysis (extra jet)  
Allow 2-4 final state jets

## DiLepton

- Dileptons ( $e/\mu$ )      - Z veto
- 1 Jet                          $- H_T = \sum_{l,jet,\ell_T} p_T > 160 \text{ GeV}$
- Missing Et ( $ee/\mu\mu$ -ch)



	Lepton Channel	Dilepton Channel
Wt	<b><math>12.6 \pm 0.9</math></b>	<b><math>7.1 \pm 0.5</math></b>
Background	<b><math>262.0 \pm 22.8</math></b>	<b><math>91.3 \pm 5.4</math></b>
Observed	<b>294</b>	<b>107</b>

## Results

Analysis	Expected limit	Observed limit
Lepton+jets	123 pb	198 pb
Dilepton	112 pb	110 pb
Combined	94 pb	158 pb

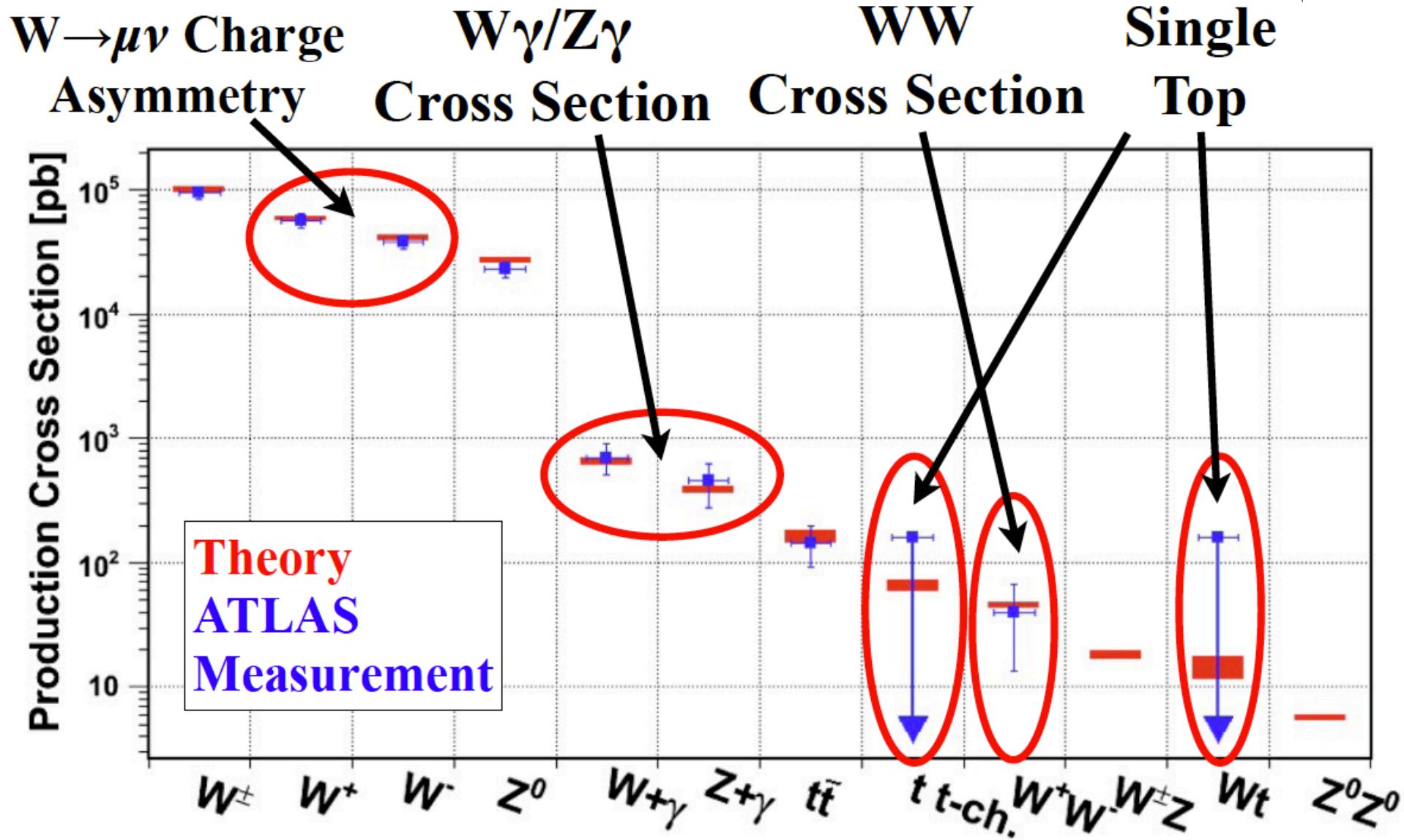
**Limiting systematics:** Jet Energy Scale,  
b-tagging efficiency, Background Modeling

## Results

- observed excess consistent w/SM prediction

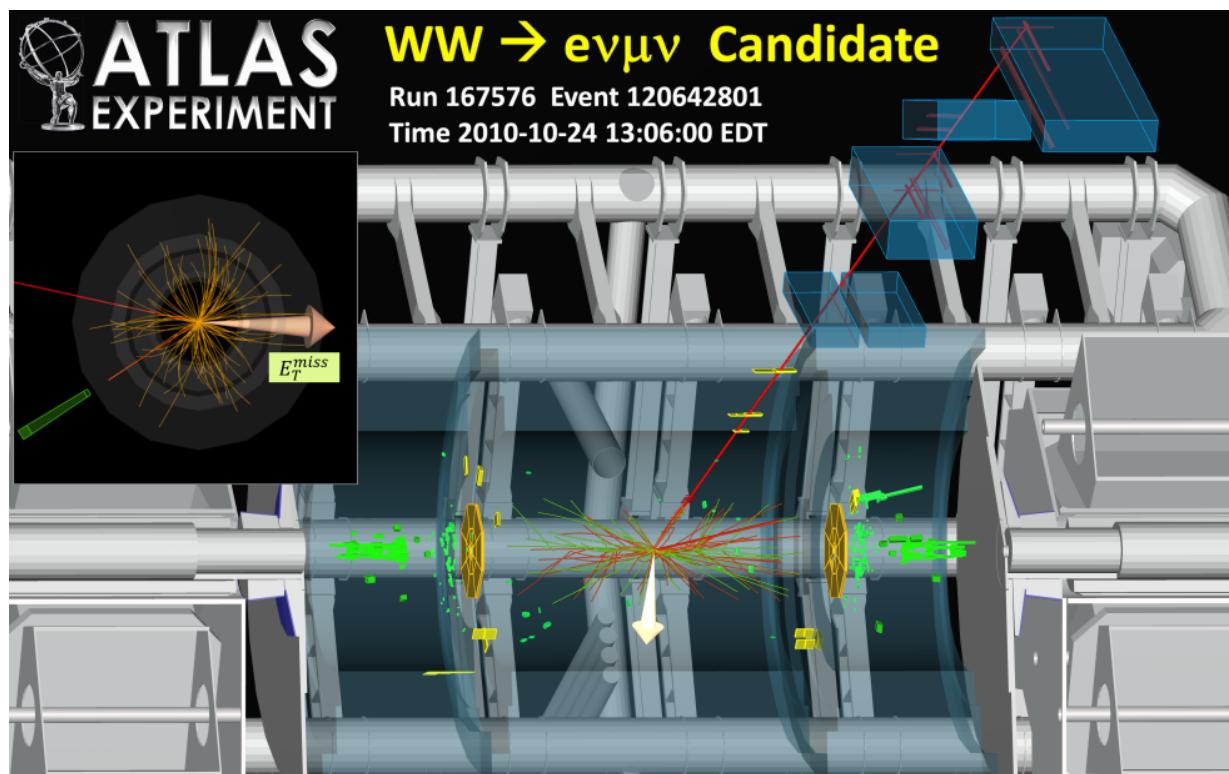


# Our "Step" Plot





# Higgs



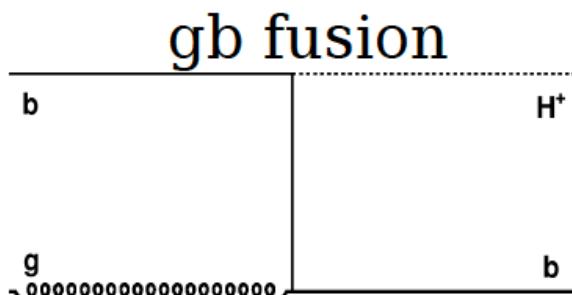
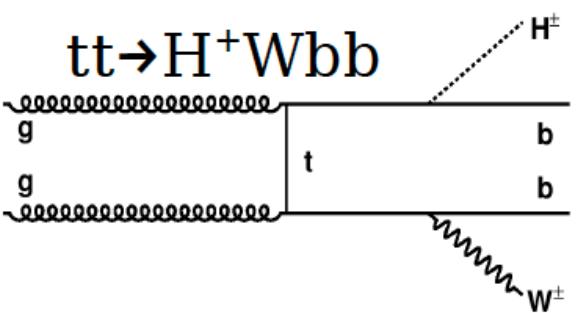
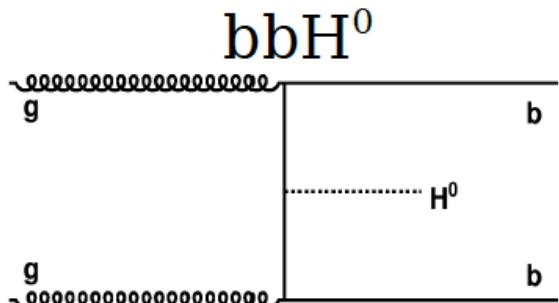
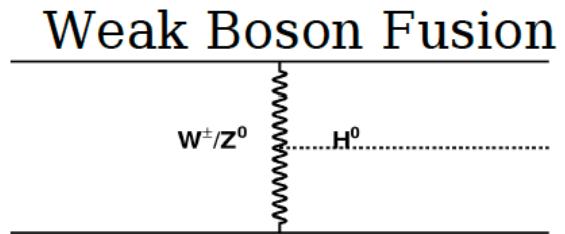
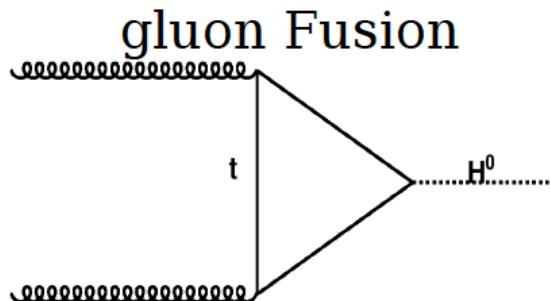
# Higgs Production at LHC



► In the Standard Model, Higgs boson production primarily through gluon fusion and Weak Boson Fusion

- Some modes (e.g.  $H \rightarrow \gamma\gamma$ ,  $bb$ ) receive contribution from  $WH/ZH/ttH$  too

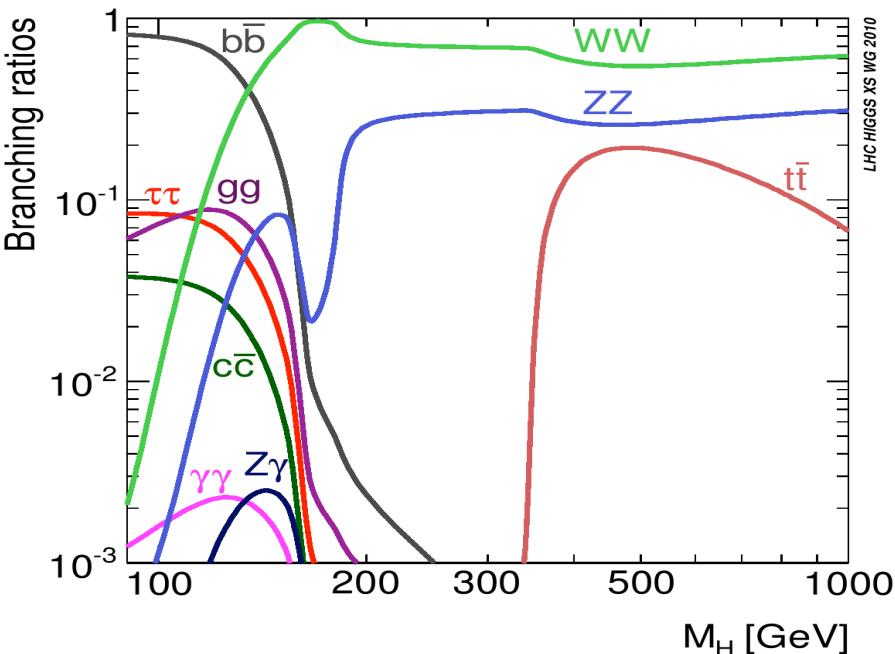
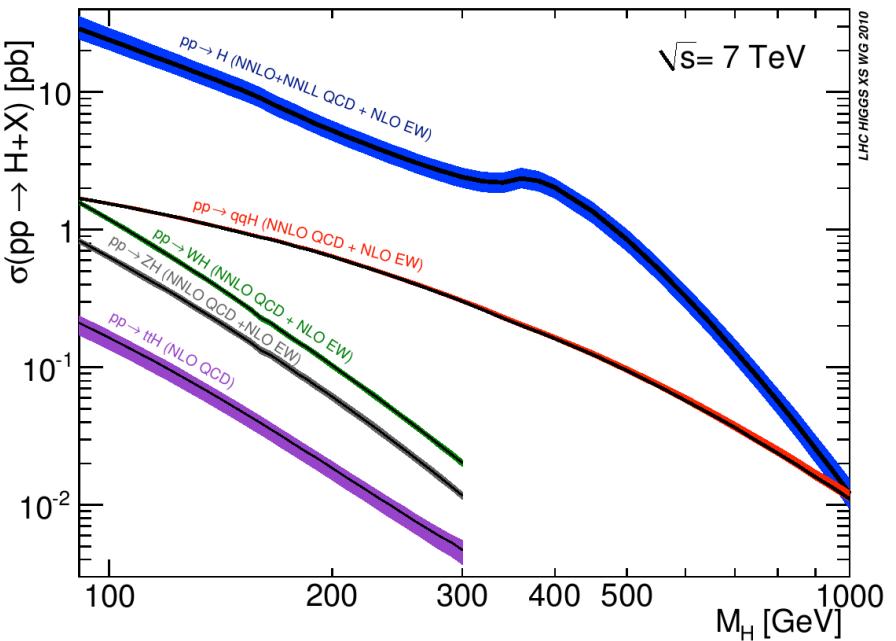
► In MSSM/2HDM,  $H^0$  is also produced in with two b quarks (if  $\tan \beta$  is large).  $H^\pm$  is produced in top decays if  $M_{H^\pm}$  is small, or in association with top (gb fusion) if  $M_{H^\pm}$  is large



# Higgs Production, Decay, Statistical Inference



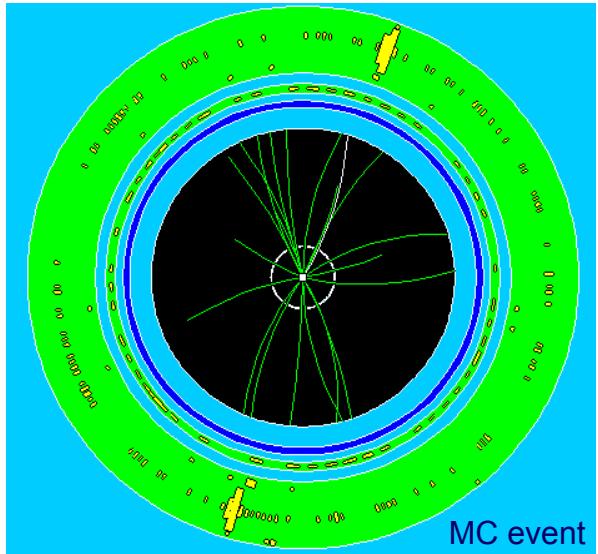
- Signal rates and theoretical uncertainties ( $m_f$ ,  $m_r$ , PDF and  $a_s$ ) based on „Handbook of LHC Higgs Cross Sections: 1. Inclusive Observables.“ arXiv:1101.0593 [hep-ph]



- Power-Constrained Limits (PCLs):
  - Profile Likelihood method: frequentist technique to set limits on  $\mu = \sigma/\sigma(\text{SM})$  with nuisance parameters for systematic uncertainties
  - Power Constraint  $CL_{S+B}$  (impose  $CL_B > 16\%$ ) i.e. if observed cross section limit smaller than median expected  $- 1\sigma$ , then quote median expected  $- 1\sigma$
  - for comparison,  $CL_S$  used at LEP and TEVATRON also shown

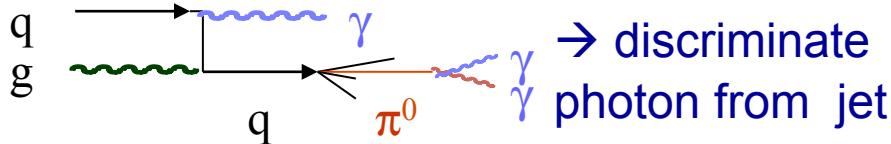


- 2 isolated photons with  $p_T > 40 / 25$  GeV



- main backgrounds:

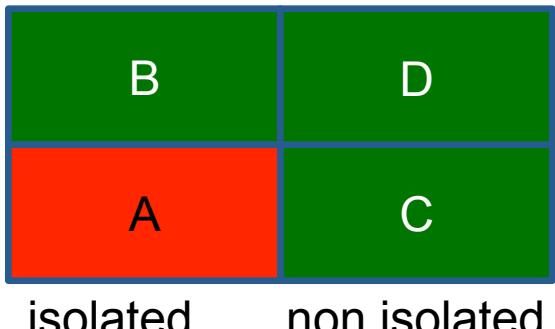
reducible:  $\gamma$ -jet and jet-jet



irreducible:  $\gamma\gamma$

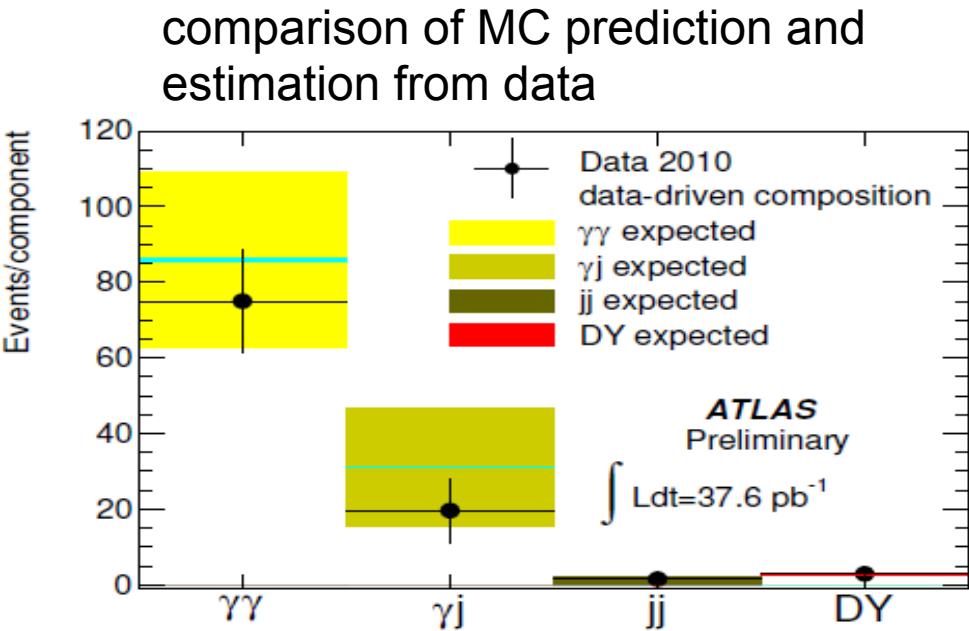


- check of backgrounds from sidebands



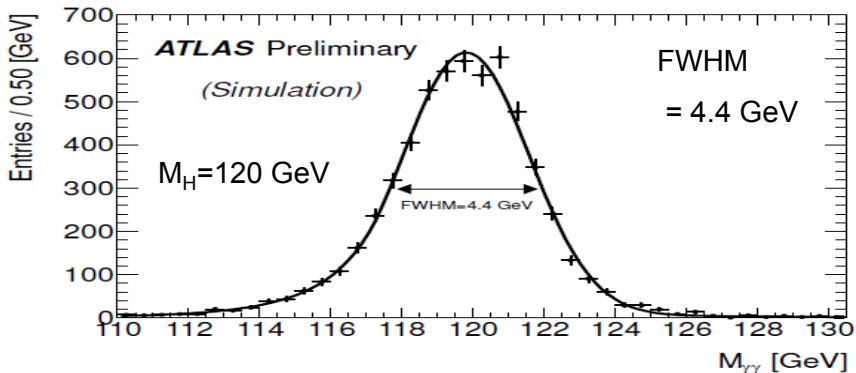
loose  $\gamma$  ID  
tight  $\gamma$  ID

Iterative  $A=B^*C/D$  method

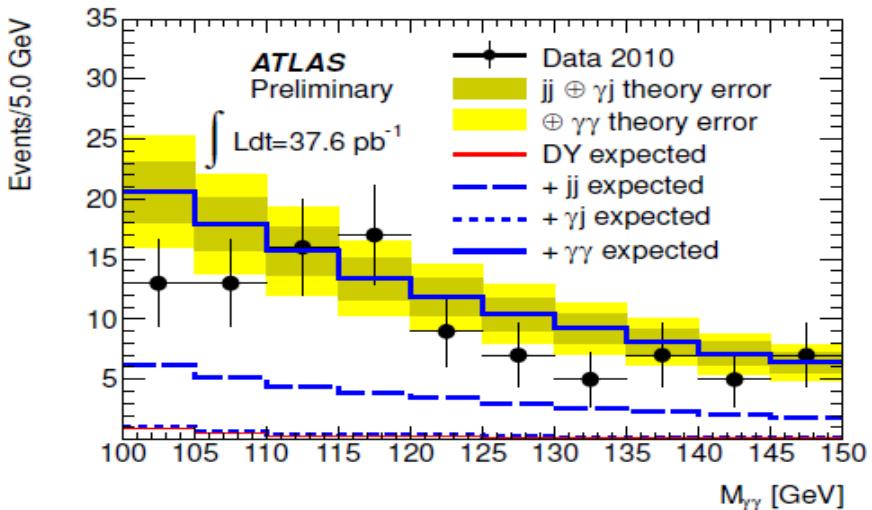




- signal mass shape described by Crystal Ball + Gaussian



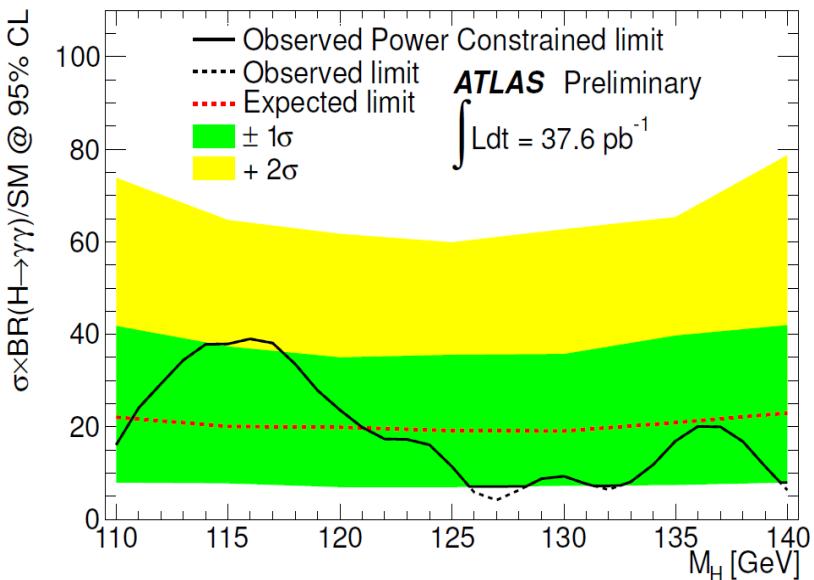
- background extraction via exponential shape with two nuisance parameters



- signal systematic uncertainties

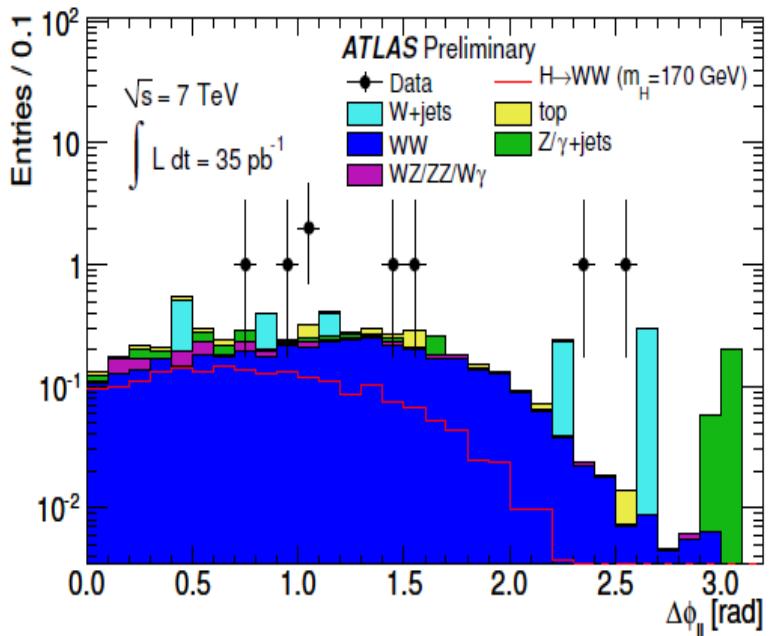
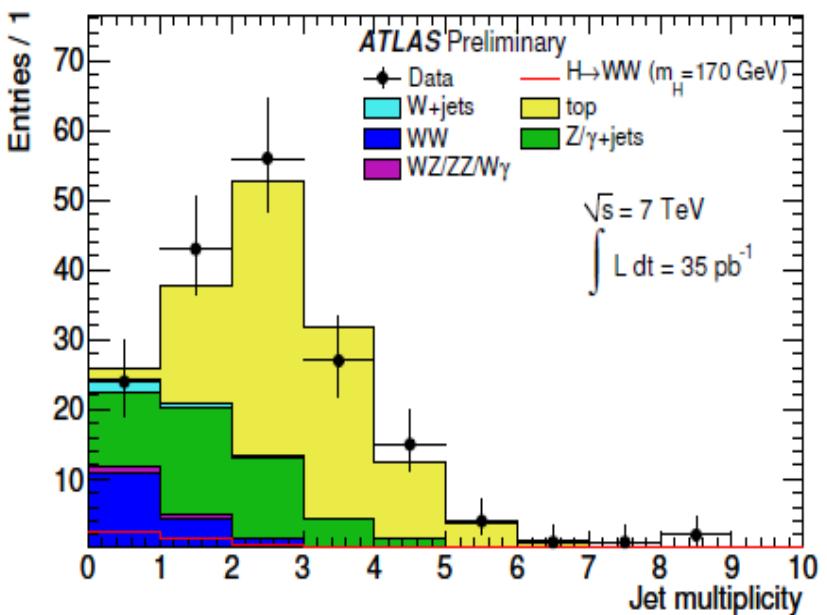
Source	Uncertainty (%)
Luminosity	$\pm 3.4$
Cross section	+20/-15
Photon identification	$\pm 11$
Photon Isolation	$\pm 10$
Trigger	+1.1/-3.7
Energy resolution	$\pm 13$ on $\sigma_M$

- exclusion limit





- production via gluon fusion + VBF considered
- backgrounds: diboson  $qq, gg \rightarrow WW, ZZ, WZ$   
 $W+jets, Z+jets, tt, \text{single top, ...}$
- preselection:
  - 2 leptons ( $e, \mu$ ),  $p_T > 20(15)$  GeV
  - $M_{\parallel} > 15$ ,  $|M_Z - M_{\parallel}| > 10$  GeV ( $ee, mm$ )
  - MET  $> 30$  GeV
  - $\Delta\phi_{\parallel} < 1.3$  (1.8) for  $M_H < 170$  ( $\geq 170$ ) GeV
- optimise sensitivity by branching in 0, 1 and 2 jets and additional topological cuts
- uncertainty on signal events  
 $0 / 1 / 2$  jets: 10 / 6 / 35 % evaluated by variation of  $m_f, m_r, \text{PDF}, a_s$  in NNLO+NNLL calculation

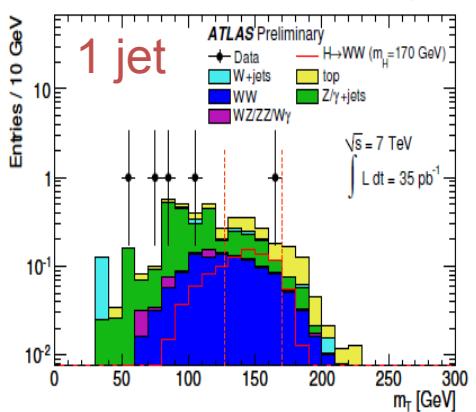
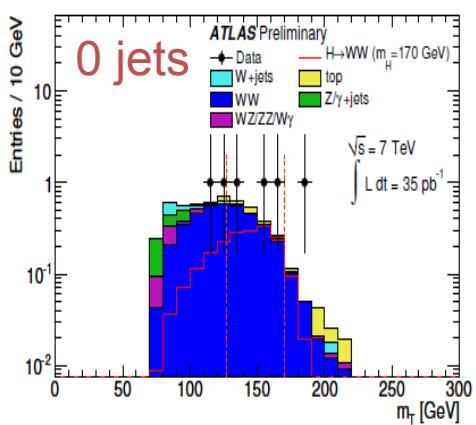




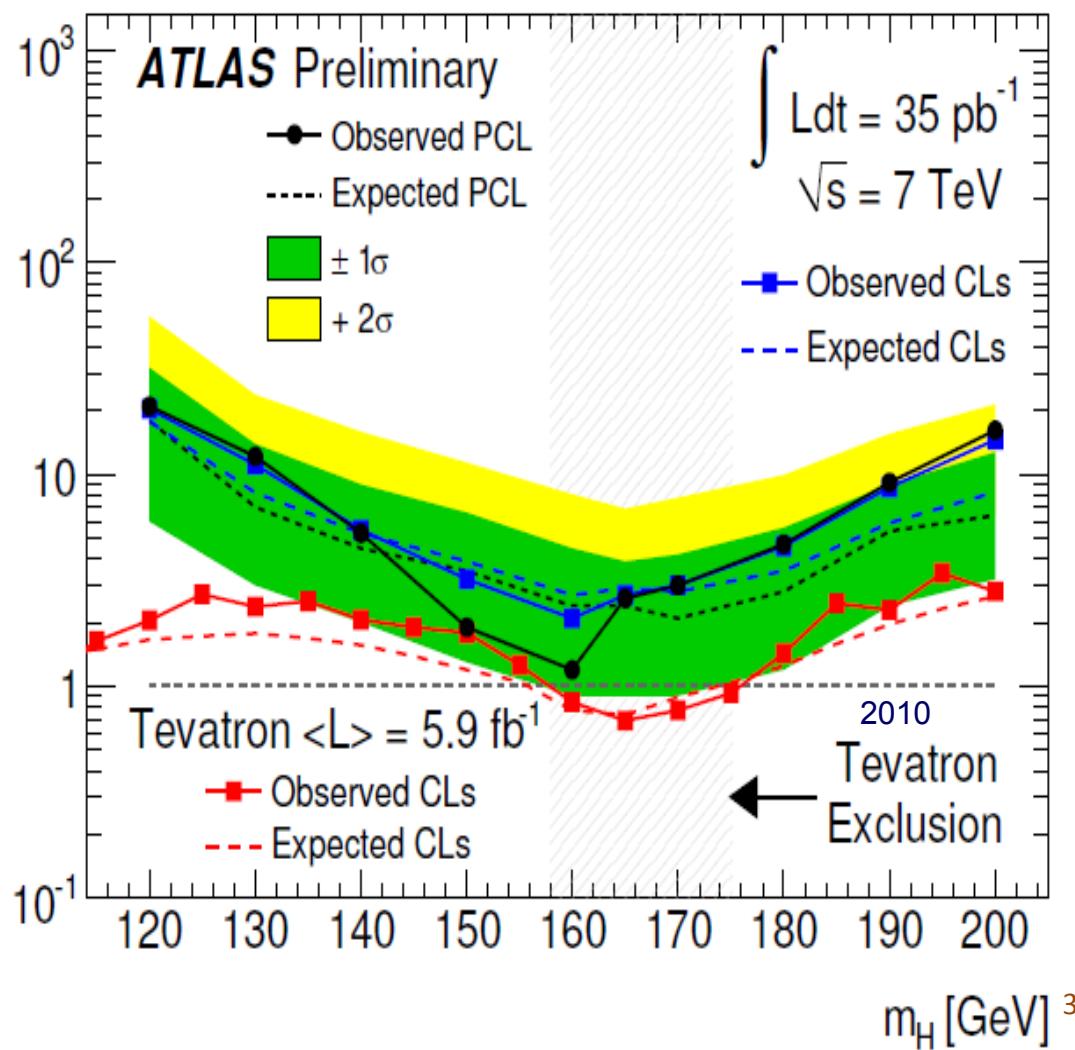
# $H \rightarrow WW^{(*)} \rightarrow \ell\nu\ell\nu$

■ final cut on transverse mass  $0.75 M_H < m_T = \sqrt{(E_T^{\ell\ell} + E_T^{\text{miss}})^2 - (\mathbf{P}_T^{\ell\ell} + \mathbf{P}_T^{\text{miss}})^2} < M_H$

	0 jet	1 jet	2jet
Data	3	1	0
BG	$1.7 \pm 0.3$	$1.3 \pm 0.5$	$0.02 \pm 0.03$
Higgs	$1.3 \pm 0.4$	$0.6 \pm 0.2$	$0.06 \pm 0.03$



■ Major backgrounds estimated from data CRs

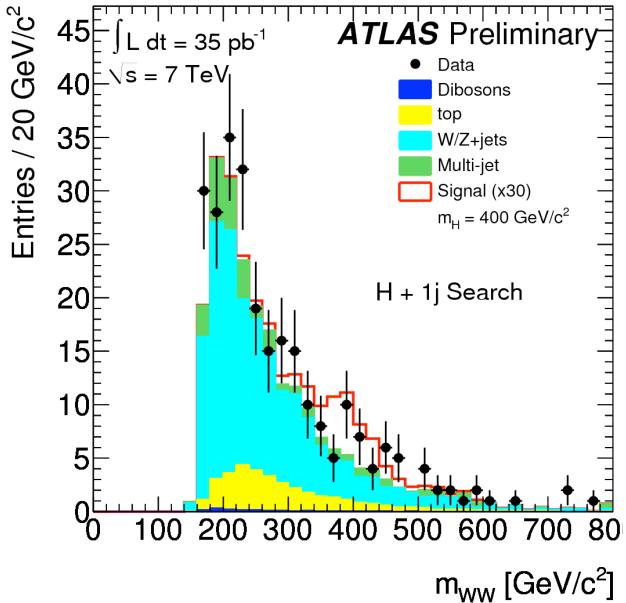
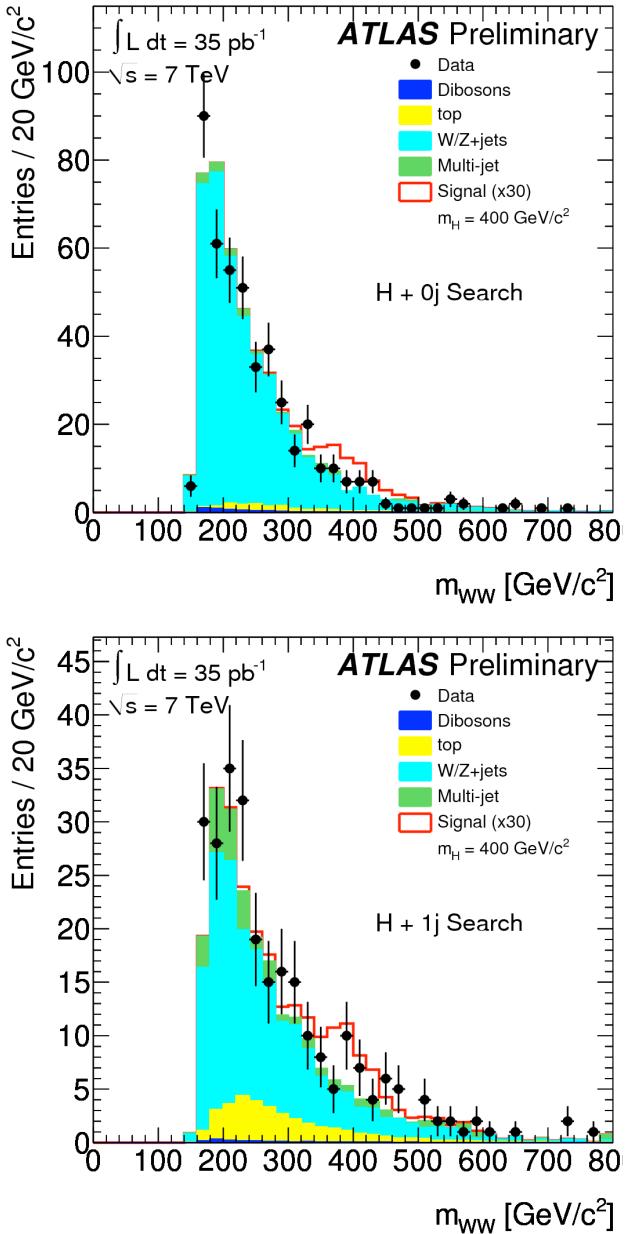




$$H \rightarrow WW^{(*)} \rightarrow \ell\nu qq$$

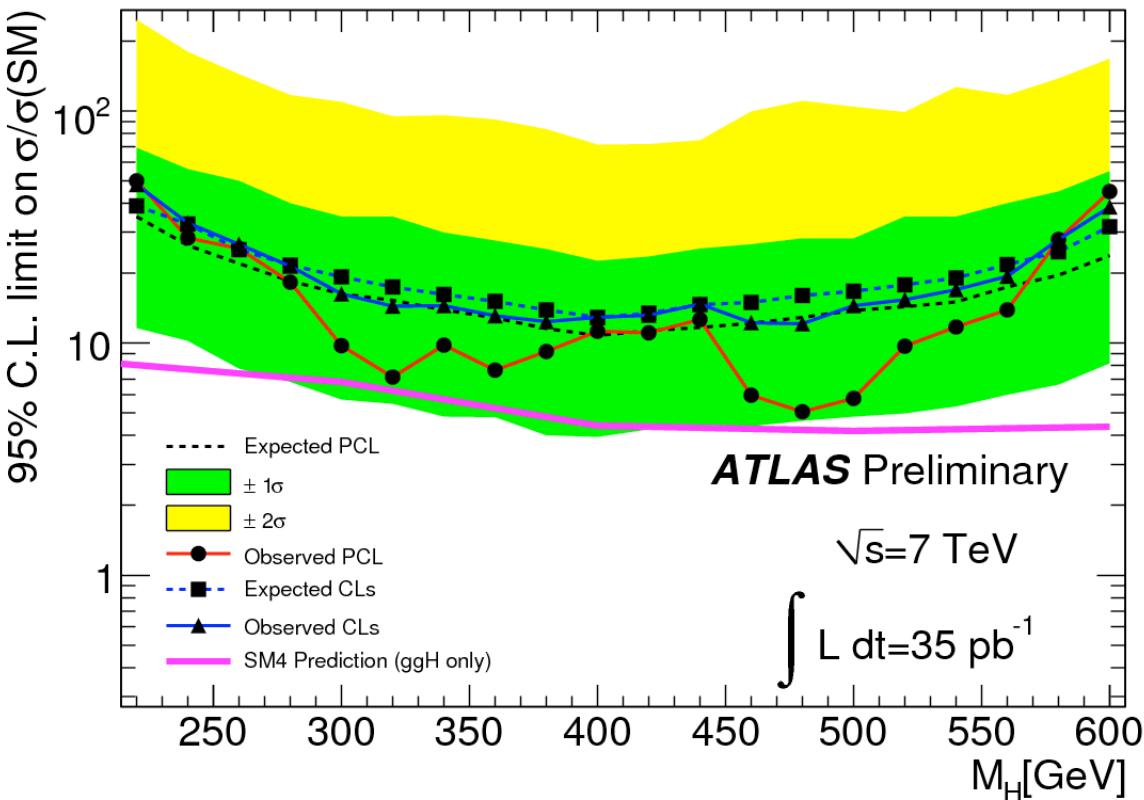


New  
Since  
Moriond!



## Signature:

- Lepton ( $e, \mu$ ) + 2 or 3 jets + MET
- Allows for full Higgs mass reconstruction
- Interesting possibility to use flavor-tagging to more fully exploit the spin correlations





$$H \rightarrow ZZ^{(*)} \rightarrow llll$$

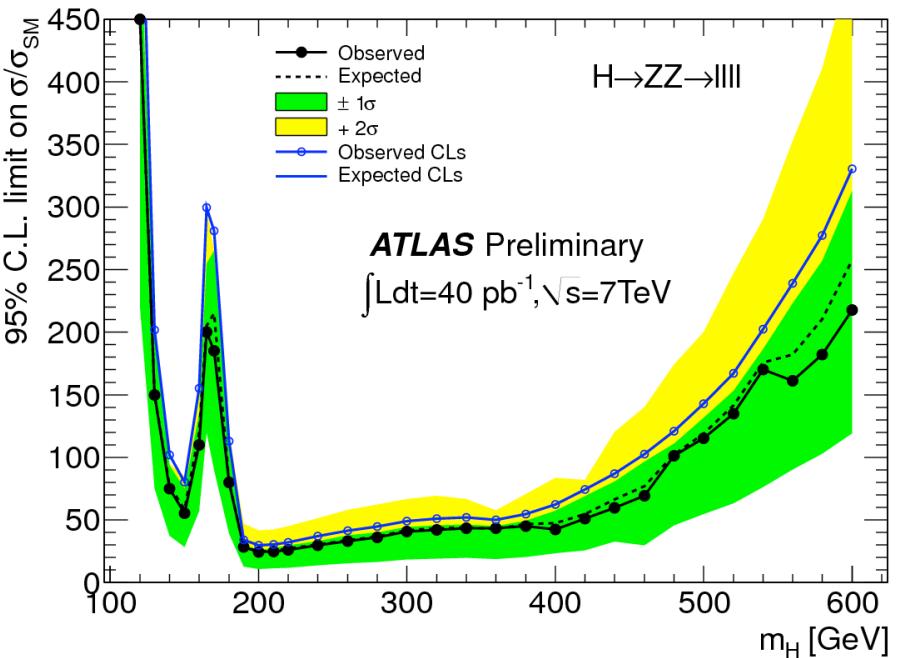
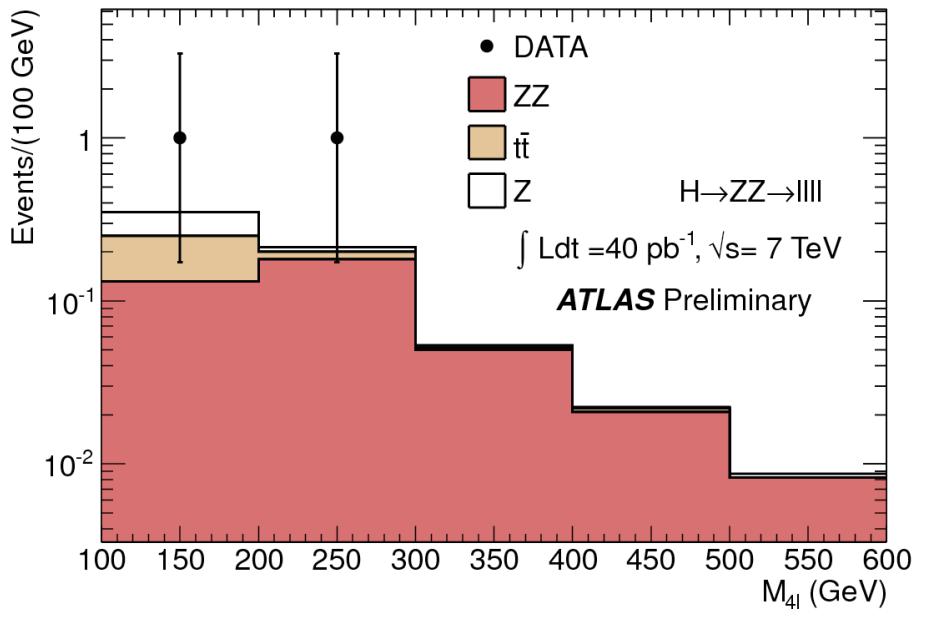
New  
Since  
Moriond!



## Signature:

- 2 pairs of same-flavor, opposite-charge leptons
- Z mass requirements
- Allows for full Higgs mass reconstruction

Selection	4μ	2e2μ	4e
Lepton quadruplet, both di-leptons $m_{2\ell} > 15$ GeV, $\geq 2$ leptons with $p_T > 20$ GeV and charge requirement	3	2	0
Leading di-lepton mass	2 (0.44)	0 (0.38)	0 (0.06)
Sub-leading di-lepton mass	2 (0.37)	0 (0.35)	0 (0.06)
$\Delta R(\ell, \ell') > 0.1$	1 (0.34)	0 (0.25)	0 (0.06)
Isolation Criteria	0 (0.17)	0 (0.18)	0 (0.06)
Impact Parameter Significance	0 (0.17)	0 (0.18)	0 (0.06)

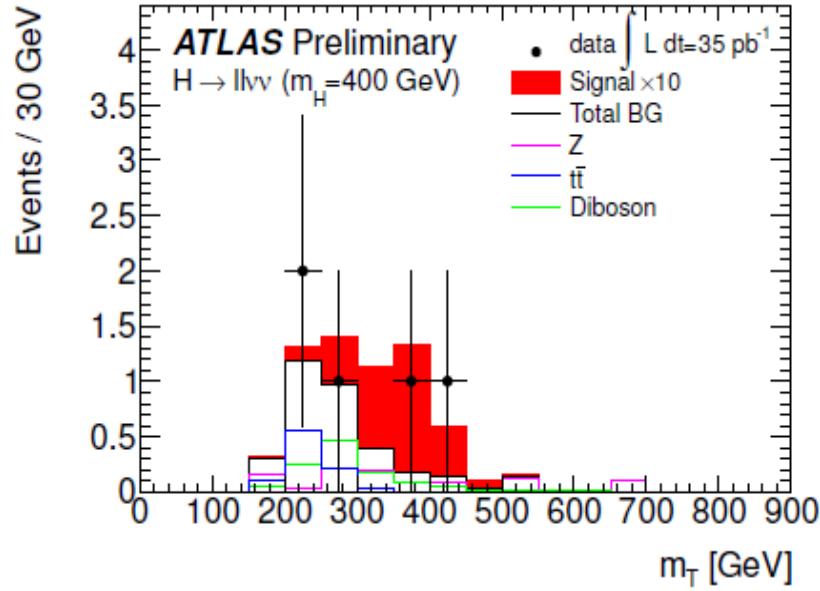
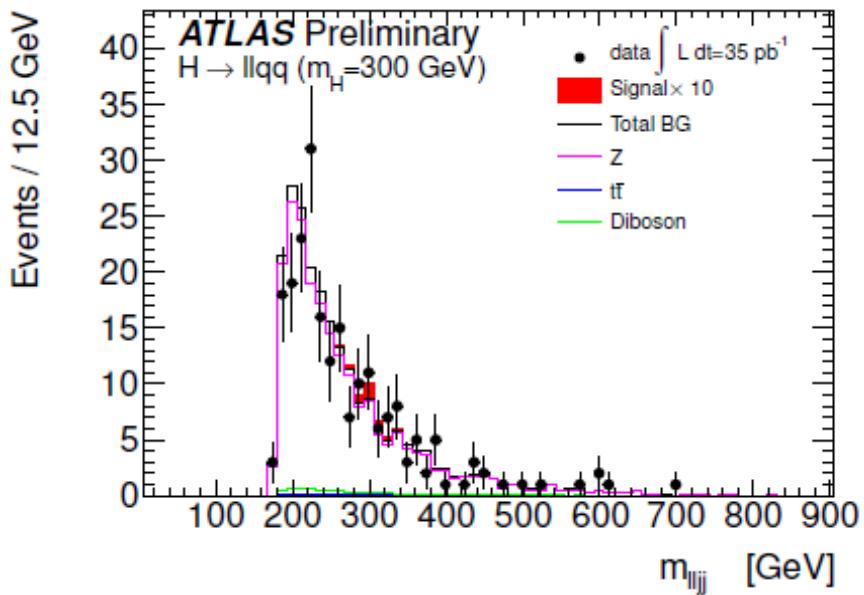


# $H \rightarrow ZZ \rightarrow \ell\ell qq, \ell\ell VV$



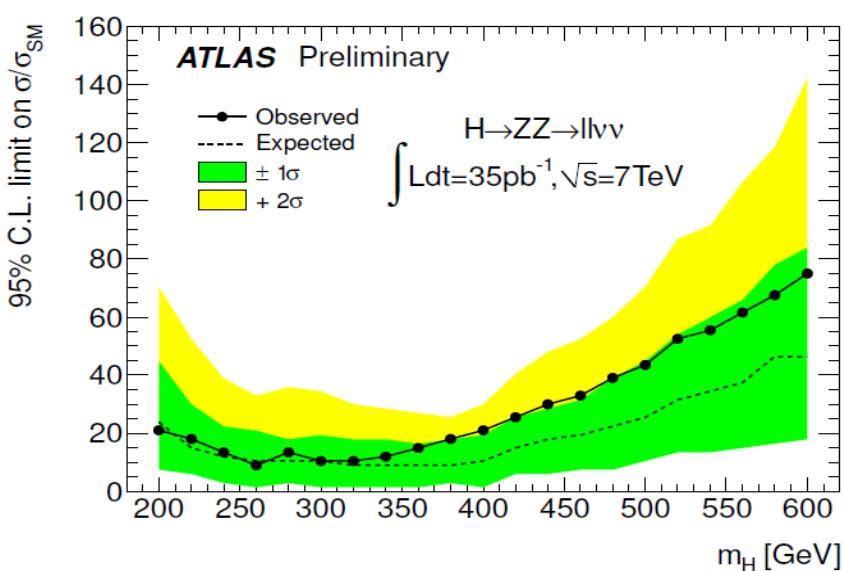
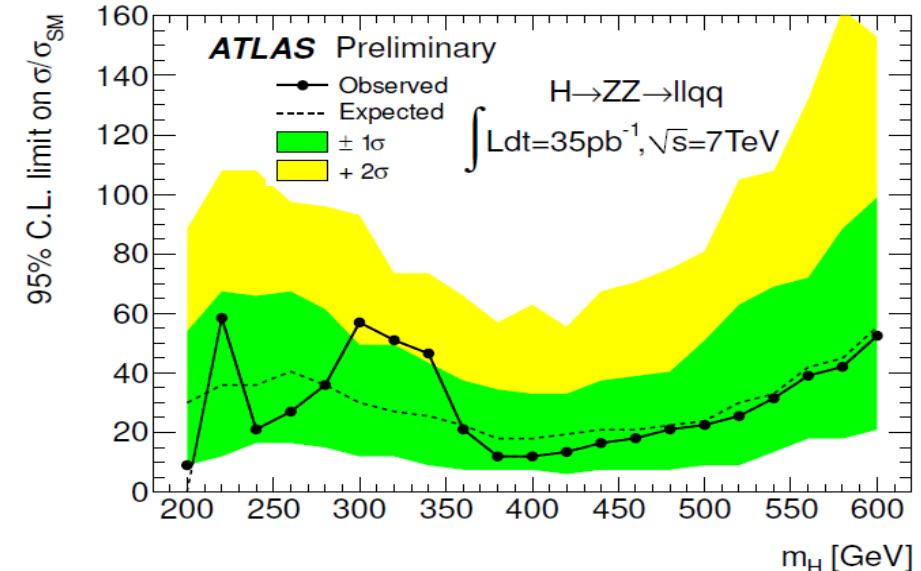
- improves sensitivity for large  $M_H$  where  $H \rightarrow ZZ \rightarrow 4$  leptons rates gets small
- 2 leptons ( $e, \mu$ ) with  $p_T > 20$  GeV,  $76$  GeV  $< M_{jj} < 106$  GeV
- $\ell\ell qq$ : final discriminant  $M_{\ell\ell jj}$  MET  $< 50$  GeV,  $70 < M_{jj} < 105$  GeV,  $M_H > 360$  GeV:  $p_T(\text{jets}) > 50$  GeV,  $\Delta\phi_{\ell\ell}, \Delta\phi_{jj} < \pi/2$
- $\ell\ell nn$ : final discriminant : transverse mass b-jet veto, MET  $> 66/82$  GeV,  $\Delta\phi_{\ell\ell} < 2.64/2.25$  for  $M_H </ \geq 260$  GeV

$$m_T^2 \equiv \left[ \sqrt{m_Z^2 + |\vec{p}_T^{\ell\ell}|^2} + \sqrt{m_Z^2 + |\vec{p}_T^{\text{miss}}|^2} \right]^2 - [\vec{p}_T^{\ell\ell} + \vec{p}_T^{\text{miss}}]^2$$



- background estimation: ZZ/WW/WZ from MC (uncertainty 15%)  
other backgrounds confirmed from sideband in  $M_{jj}$  and  $M_{\ell\ell}$  and reversed cuts  
 $\sigma(Z) = 5\%$     $\sigma(t\bar{t}) = 25\%$     $\sigma(W) = 50\%$     $\sigma(\text{multijet}) = 50\%$

# $H \rightarrow ZZ \rightarrow \ell\ell qq, \ell\ell VV$



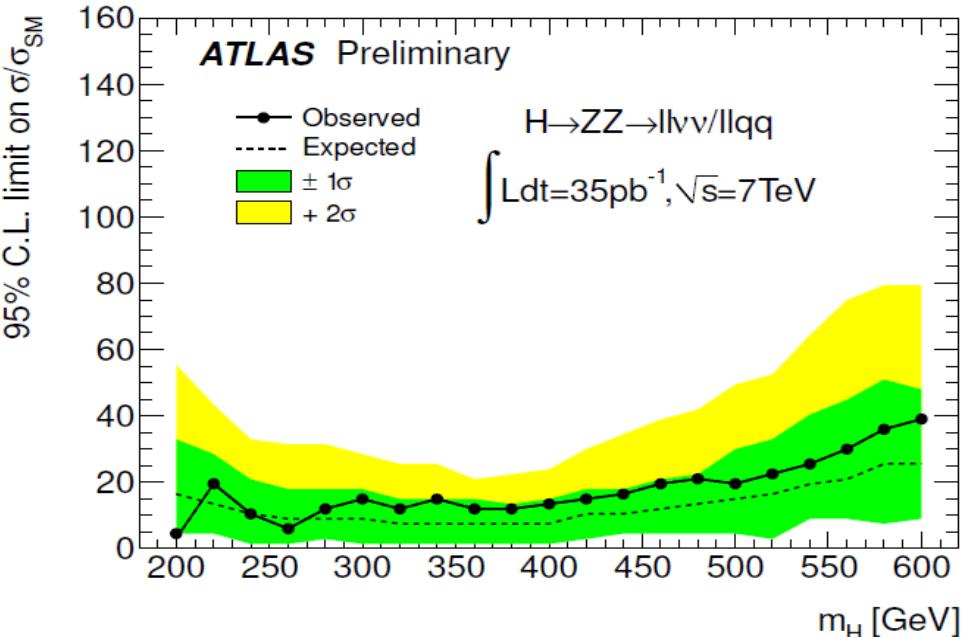
- combination of both channels:  
expected  $6.5$  to  $24.5 \times \sigma_{SM}$   
observed  $3.5$  to  $39 \times \sigma_{SM}$

signal uncertainties:

theoretical : 17%

experimental : 20 to 25%

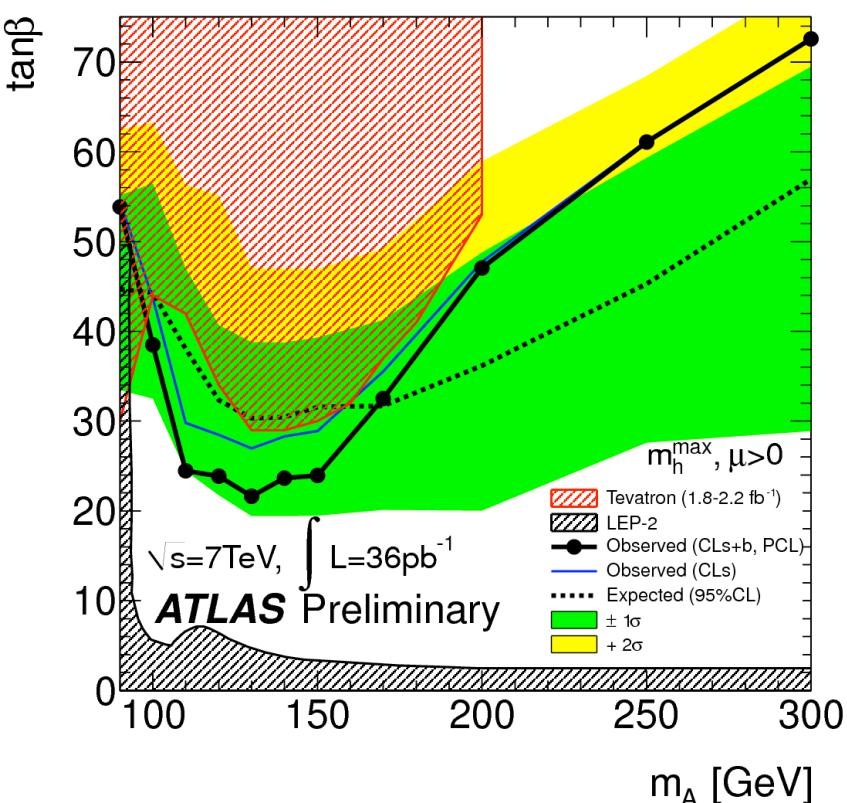
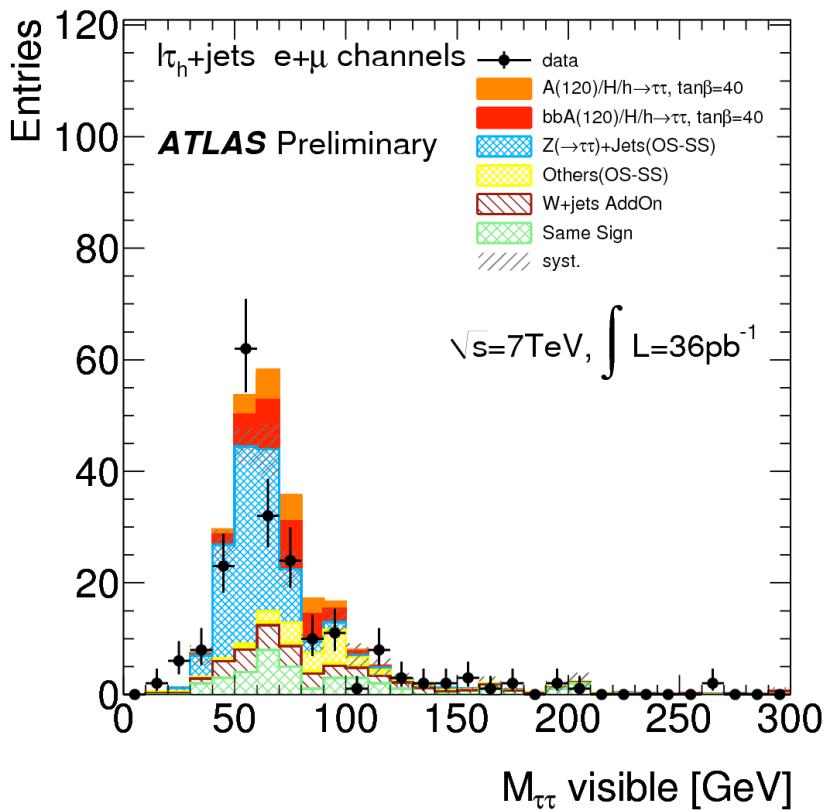
+ shape uncertainties





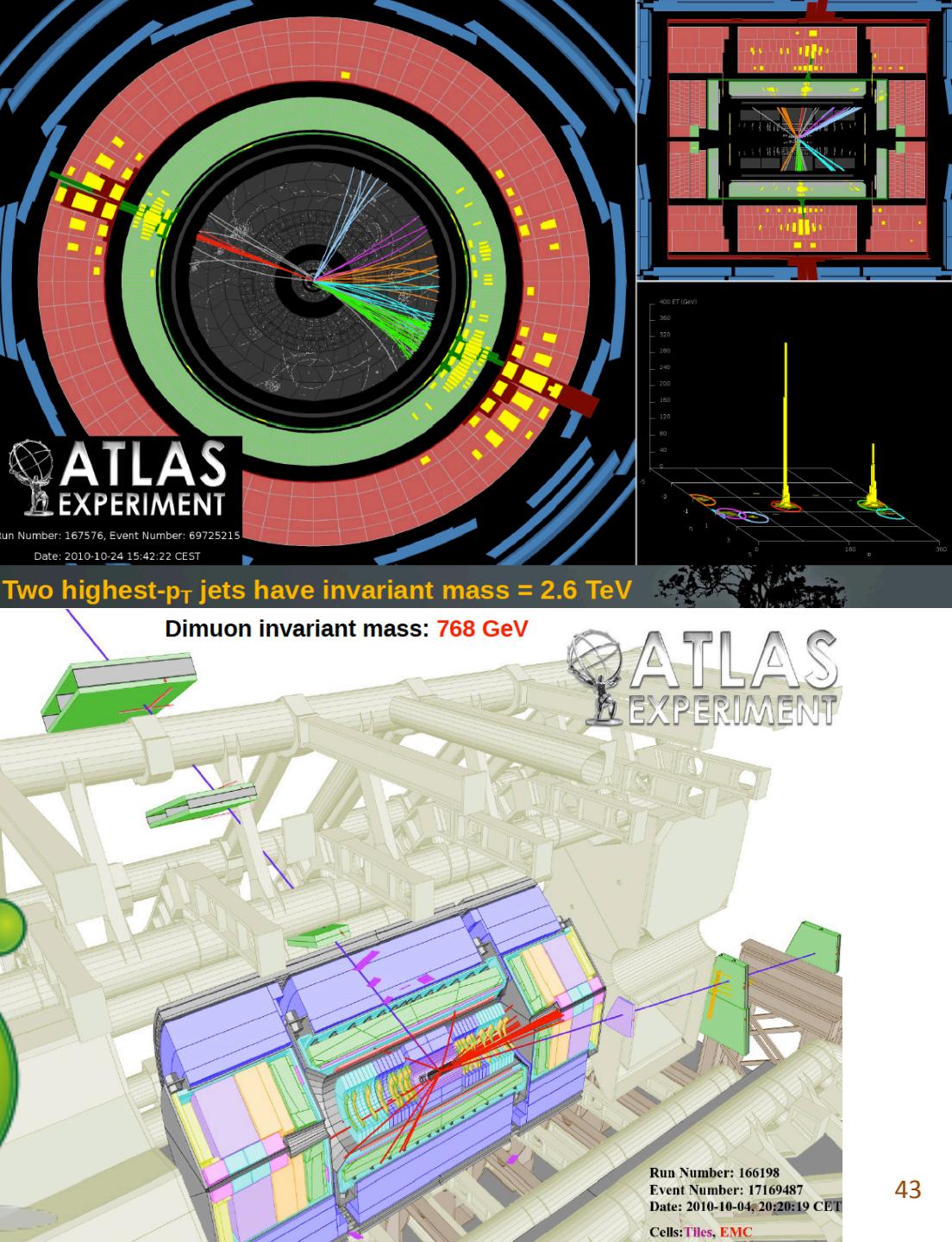
► ATLAS analysis includes only  $\tau\tau \rightarrow lh$ , and is based on invariant mass of visible  $\tau$  decay products

- $Z \rightarrow \tau\tau$  Monte Carlo checked by replacing muons in  $Z \rightarrow \mu\mu$  data events with simulated taus.
- QCD/W+jets estimated with same-sign control sample





# SUSY & Exotica





# SUSY Searches



- Try to be as model-independent as possible - search for all conceivable signatures!
- In R-Parity conserving models, Lightest Supersymmetric Particle (LSP) is stable.  
⇒ Missing transverse energy ( $E_T^{\text{miss}}$ ).
- Coloured sparticles more likely to be produced - (model-dependent) cascade decays to LSP.  
⇒ High  $p_T$  jets.  
⇒ Possibly high  $p_T$  isolated leptons.
- Third-generation squarks may be lighter (therefore higher production cross-section).  
⇒ Possibly b-jets.

**This talk:** interpretation in context of mSUGRA

Also have interpretations in more general 24-parameter MSSM framework



# SUSY: 0 lepton analysis

- Define variables:

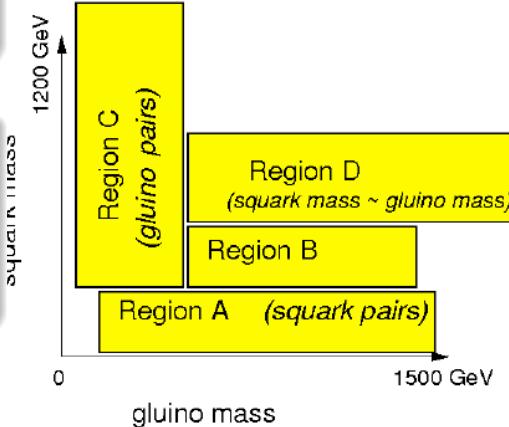
Effective mass

$$m_{\text{eff}} \equiv \sum_{i=1}^n |\vec{p}_T^i| + E_T^{\text{miss}}$$

Stransverse mass

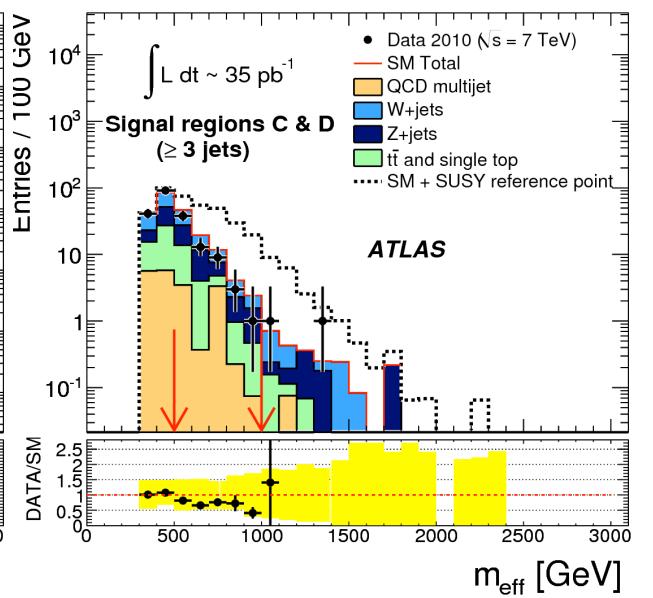
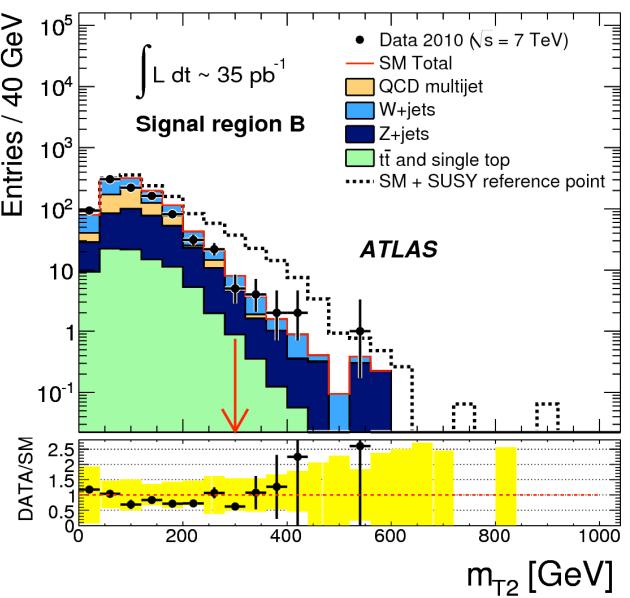
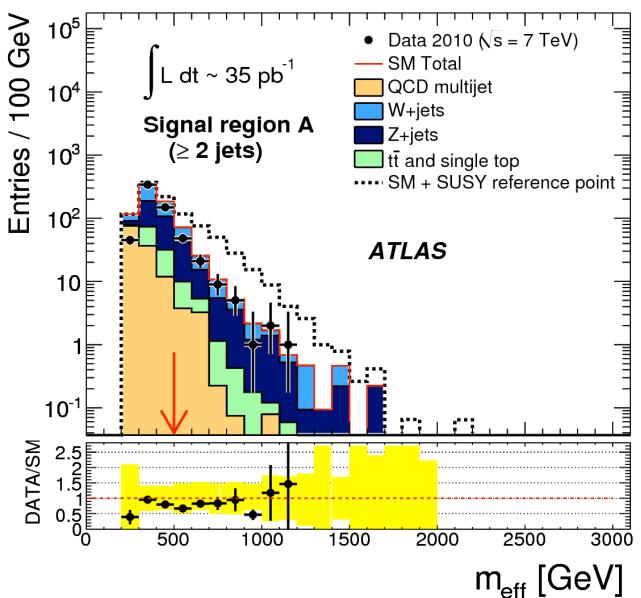
$$\begin{aligned} m_{T2}(\vec{p}_T^{(1)}, \vec{p}_T^{(2)}, \vec{p}_T) &\equiv \\ \min_{g_T^{(1)}+g_T^{(2)}=E_T^{\text{miss}}} \{ &\max(m_T(\vec{p}_T^{(1)}, \vec{q}_T^{(1)}), m_T(\vec{p}_T^{(2)}, \vec{q}_T^{(2)})) \} \\ m_T^2(\vec{p}_T^{(i)}, \vec{q}_T^{(i)}) &\equiv 2|\vec{p}_T^{(i)}||\vec{q}_T^{(i)}| - 2\vec{p}_T^{(i)}\cdot\vec{q}_T^{(i)} \end{aligned}$$

- Define four signal regions:



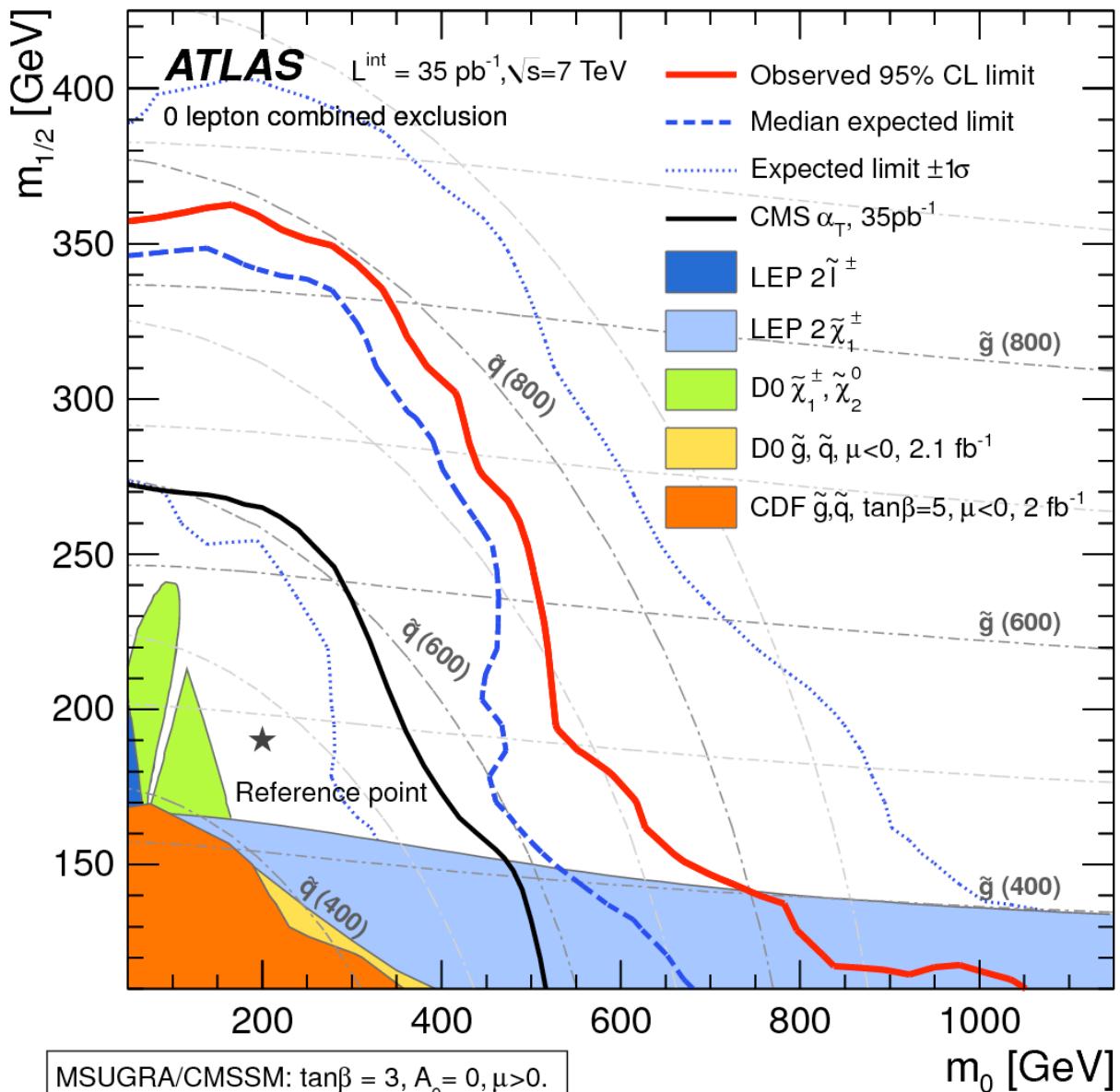
- Classification almost model-independent.

	A	B	C	D
Njets	$\geq 2$	$\geq 2$	$\geq 3$	$\geq 3$
Leading jet $p_T$ (GeV)	$> 120$	$> 120$	$> 120$	$> 120$
Other jet(s) $p_T$ (GeV)	$> 40$	$> 40$	$> 40$	$> 40$
$E_T^{\text{miss}}$ (GeV)	$> 100$	$> 100$	$> 100$	$> 100$
$\Delta\phi(\text{jet}, \vec{p}_T^{\text{miss}})$	$> 0.4$	$> 0.4$	$> 0.4$	$> 0.4$
$E_T^{\text{miss}}/m_{\text{eff}}$	$> 0.3$	-	$> 0.25$	$> 0.25$
$m_{\text{eff}}$ (GeV)	$> 500$	-	$> 500$	$> 1000$
$m_{T2}$ (GeV)	-	$> 300$	-	-





# SUSY: 0 lepton analysis



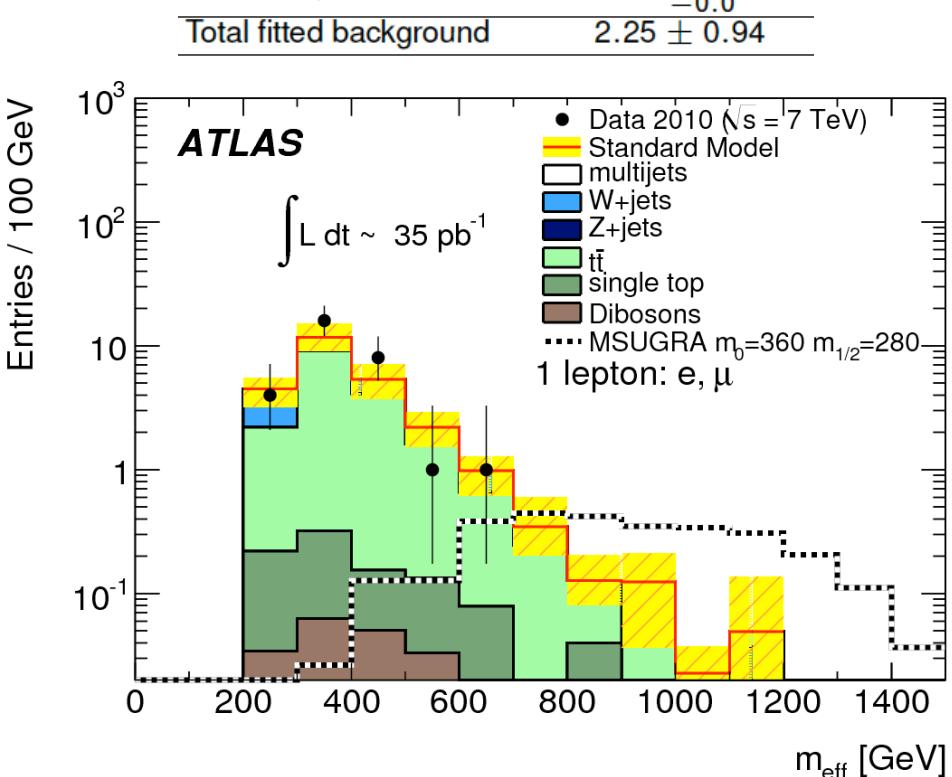
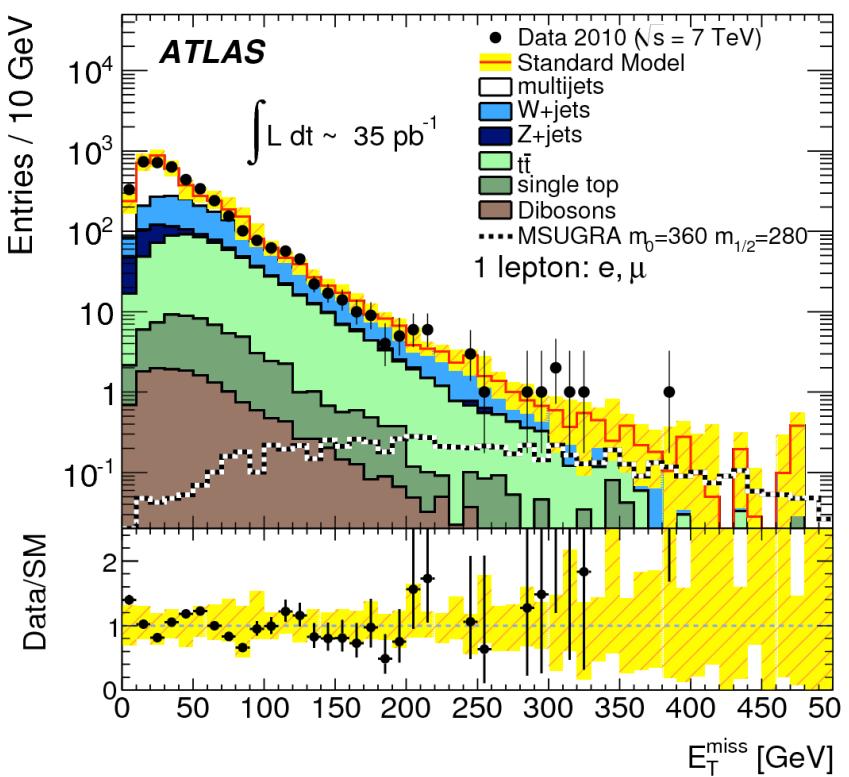
If  $m_{\tilde{q}} = m_{\tilde{g}}$   
exclude  $m_{\tilde{q}, \tilde{g}} < 775 \text{ GeV}$ .

- Exclusion limit quite insensitive to  $\text{sign}(\mu)$ ,  $\tan\beta$ , and  $A_0$ .

# SUSY: 1 lepton analysis

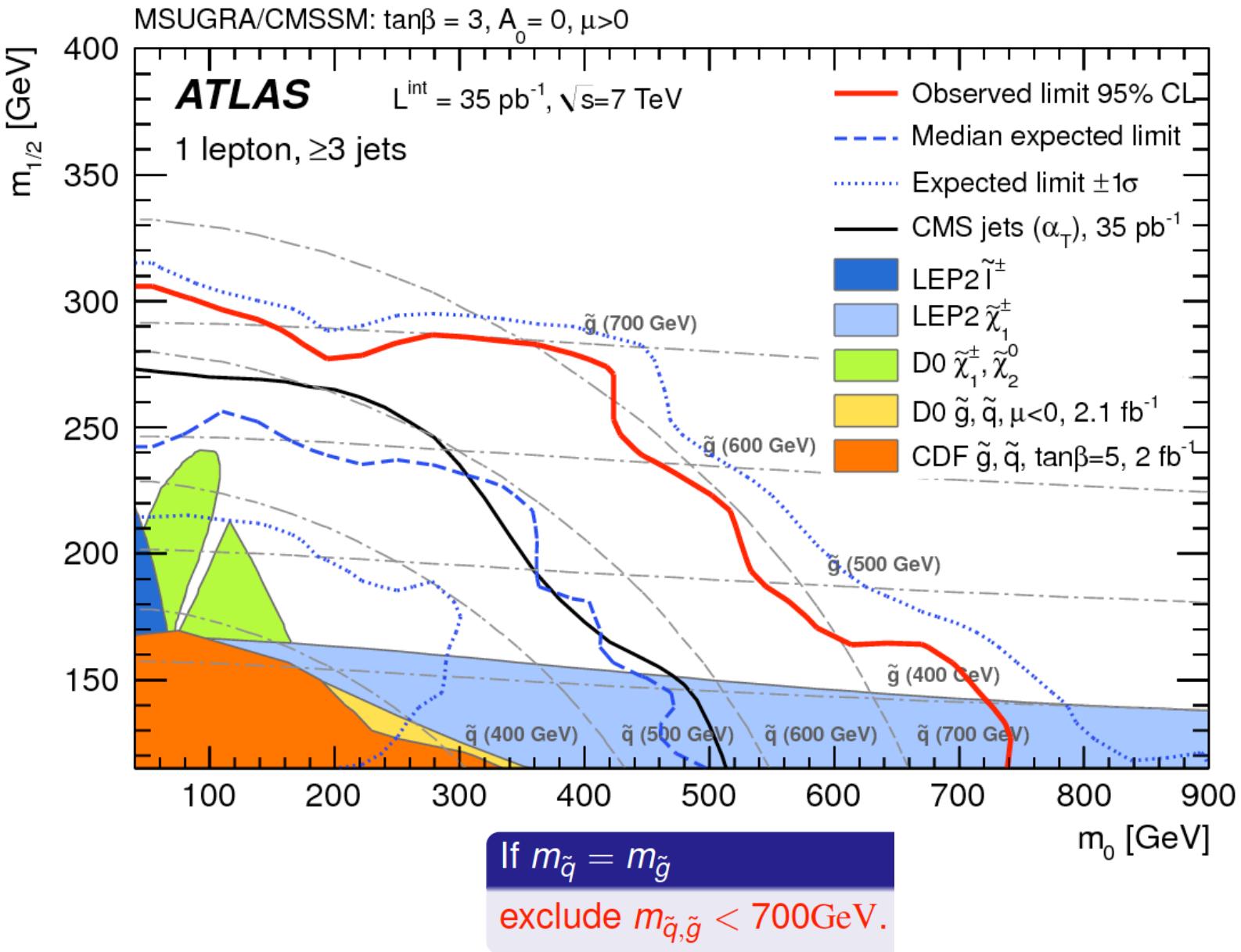


- Require exactly 1 lepton ( $p_T > 20\text{GeV}$ ), and at least 3 jets ( $p_T > 60, 30, 30\text{GeV}$ )
- $E_T^{\text{miss}} > 80\text{GeV}$
- $m_T \equiv \sqrt{2p_T^l E_T^{\text{miss}} (1 - \cos(\Delta\phi(l, E_T^{\text{miss}})))} > 100\text{GeV}$
- $m_{\text{eff}} \equiv \sum_{i=1}^3 p_T^{jet_i} + p_T^{lep} + E_T^{\text{miss}} > 500\text{GeV}$
- $E_T^{\text{miss}} > 0.25 \times m_{\text{eff}}$



	Electron channel	Signal region
Observed events		1
Fitted top events	$1.34 \pm 0.52(1.29)$	
Fitted $W/Z$ events	$0.47 \pm 0.40(0.46)$	
Fitted QCD events	$0.0^{+0.3}_{-0.0}$	
Total fitted background	$1.81 \pm 0.75$	
	Muon channel	Signal region
Observed events		1
Fitted top events	$1.76 \pm 0.67(1.39)$	
Fitted $W/Z$ events	$0.49 \pm 0.36(0.71)$	
Fitted QCD events	$0.0^{+0.5}_{-0.0}$	
Total fitted background	$2.25 \pm 0.94$	

# SUSY: 1 lepton analysis



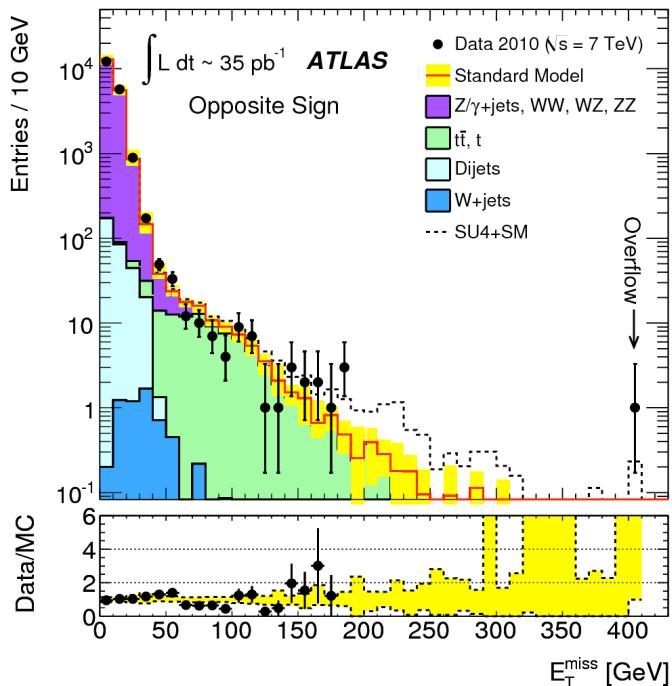


# SUSY: 2 lepton analysis

- Two analyses, looking for opposite-sign (OS) and same-sign (SS) dilepton events.

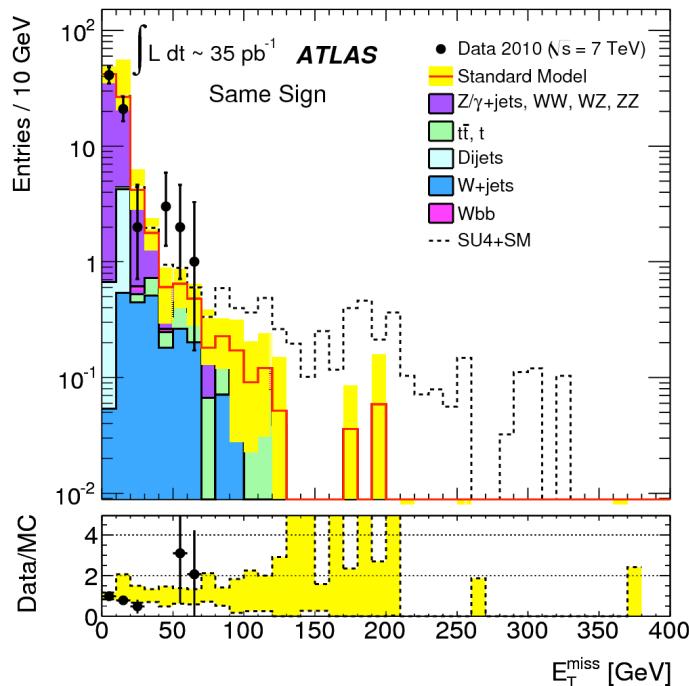
## Opposite-sign

- Signal region:  $E_T^{\text{miss}} > 150\text{GeV}$
- Main bkg:  $t\bar{t}$ ,  $Z+\text{jets}$

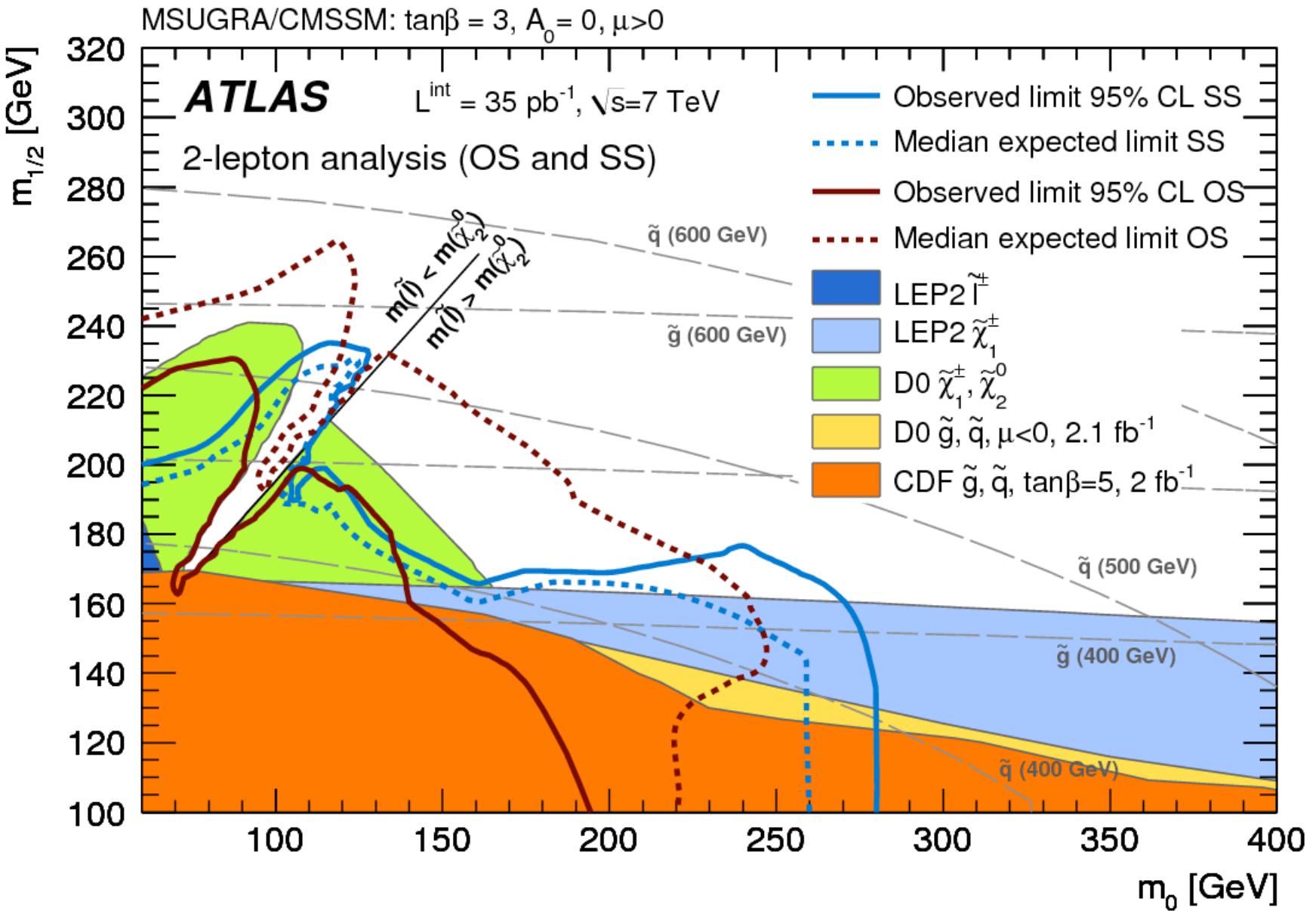


## Same-sign

- Signal region:  $E_T^{\text{miss}} > 100\text{GeV}$
- Main bkg: Fake leptons



# SUSY: 2 lepton analysis

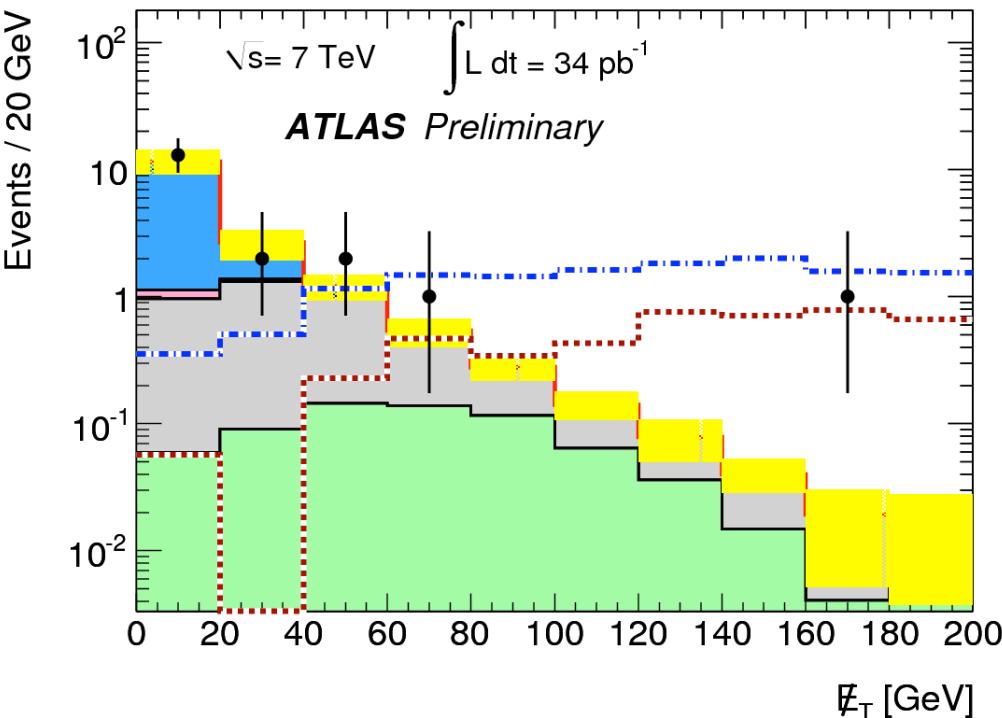




# SUSY: $\geq 3$ lepton analysis

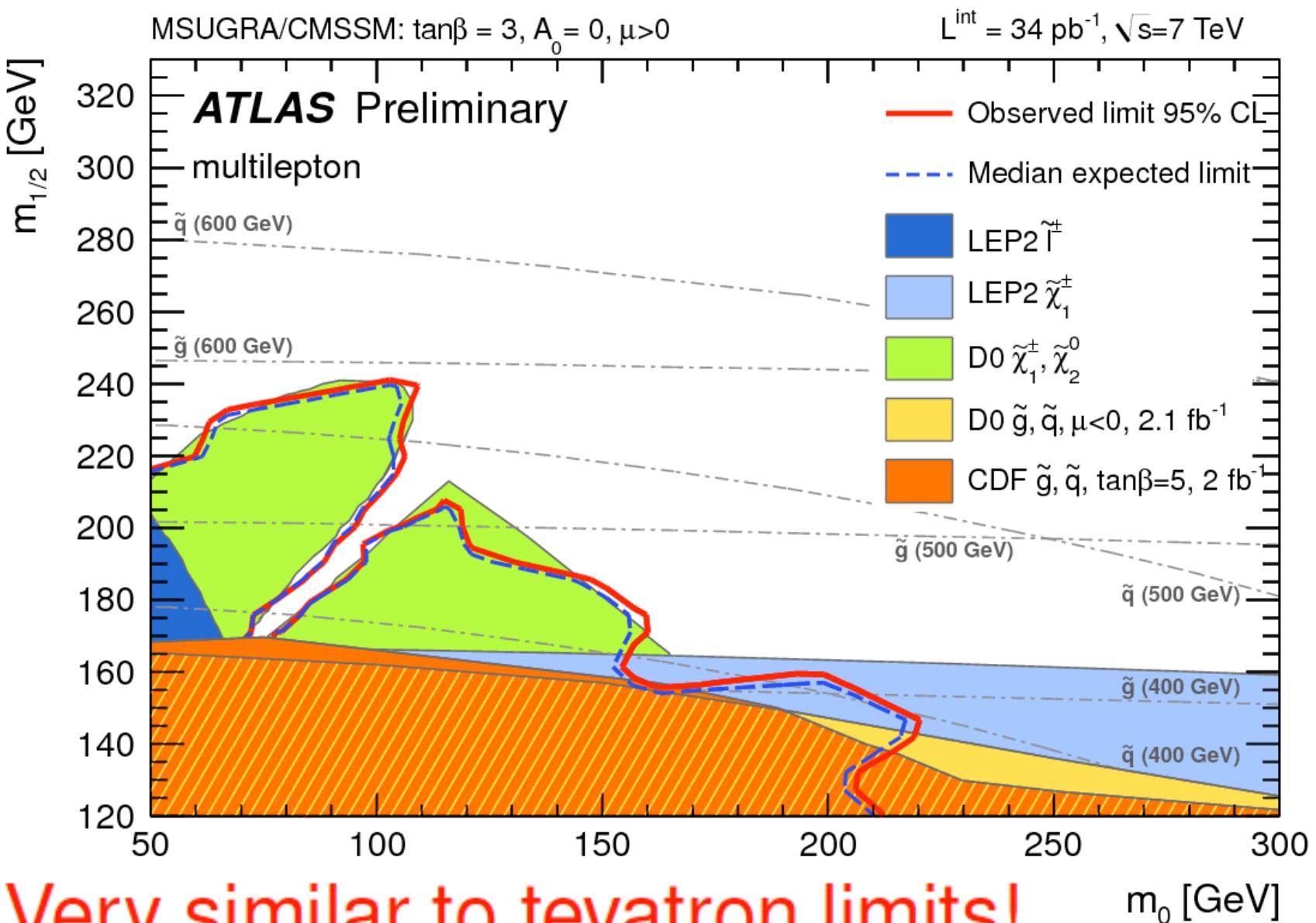


- Three-lepton final states are “golden” channel at Tevatron.
- Expect very low backgrounds!
- Require at least three electrons or muons, any charge and flavour combination .
  - $p_T$ lepton  $> 20\text{GeV}$  (or  $10\text{GeV}$  for third lepton if it is a  $\mu$ ).
- At least two jets with  $p_T > 50\text{GeV}$ , and  $E_T^{\text{miss}} > 50\text{GeV}$ .
- Veto same-flavour-opposite-sign pairs with invariant mass close to nominal  $Z$ -mass, and at low mass to suppress Drell-Yan backgrounds.



	Total	$eee$	$ee\mu$	$e\mu\mu$	$\mu\mu\mu$
$t\bar{t}$	$0.68 \pm 0.16$	$0.032 \pm 0.016$	$0.24 \pm 0.07$	$0.31 \pm 0.08$	$0.096 \pm 0.030$
$Z$	$15.6 \pm 1.3$	$3.8 \pm 0.8$	$1.60 \pm 0.34$	$8 \pm 1$	$2.4 \pm 0.4$
Other backgrounds	$0.28 \pm 0.13$	$0.02 \pm 0.14$	$0.03 \pm 0.06$	$0.21 \pm 0.09$	$0.01 \pm 0.11$
Total SM	$16.6 \pm 1.3$	$3.8 \pm 0.8$	$1.9 \pm 0.4$	$8 \pm 1$	$2.5 \pm 0.4$
Data	19	2	1	10	6

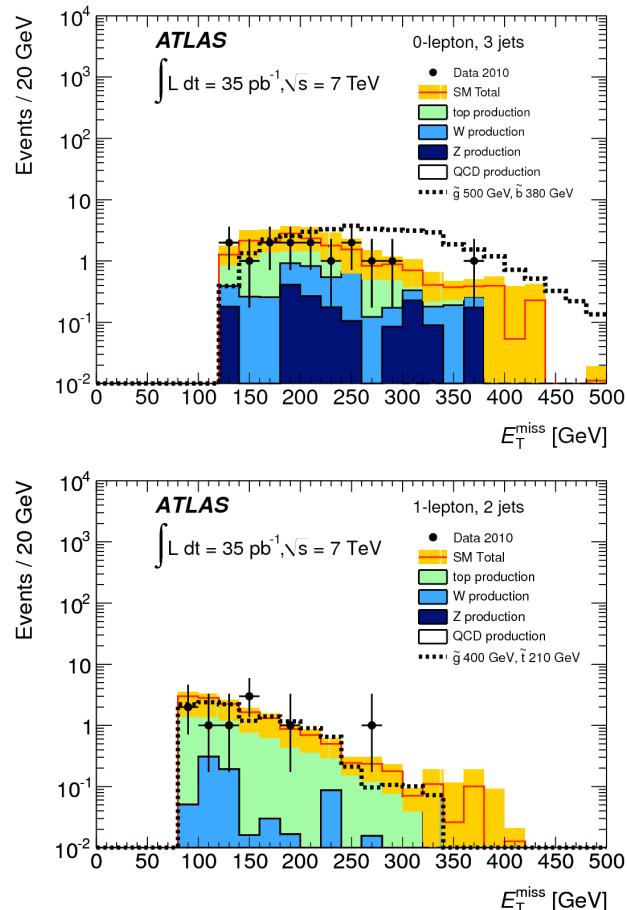
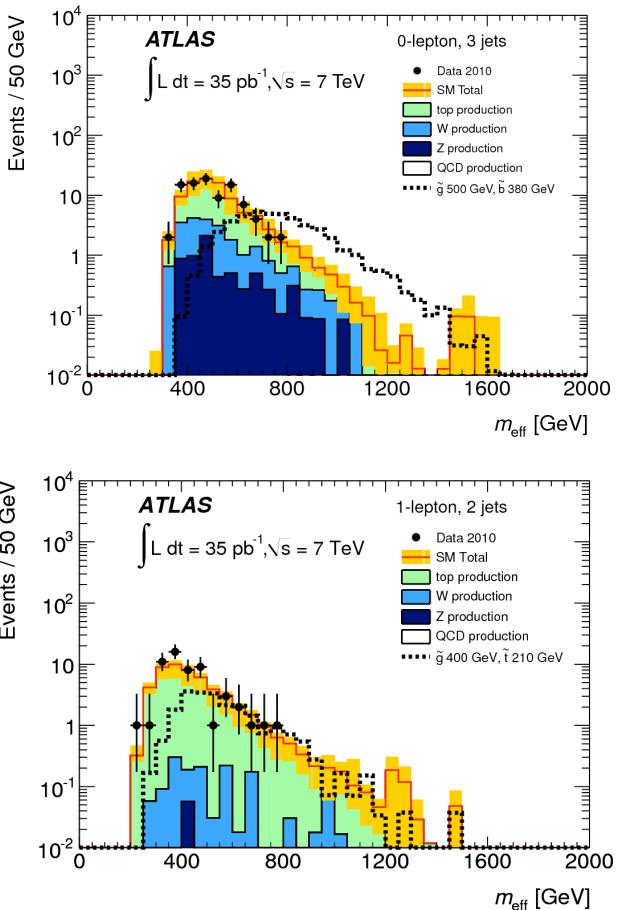
# SUSY: $\geq 3$ lepton analysis



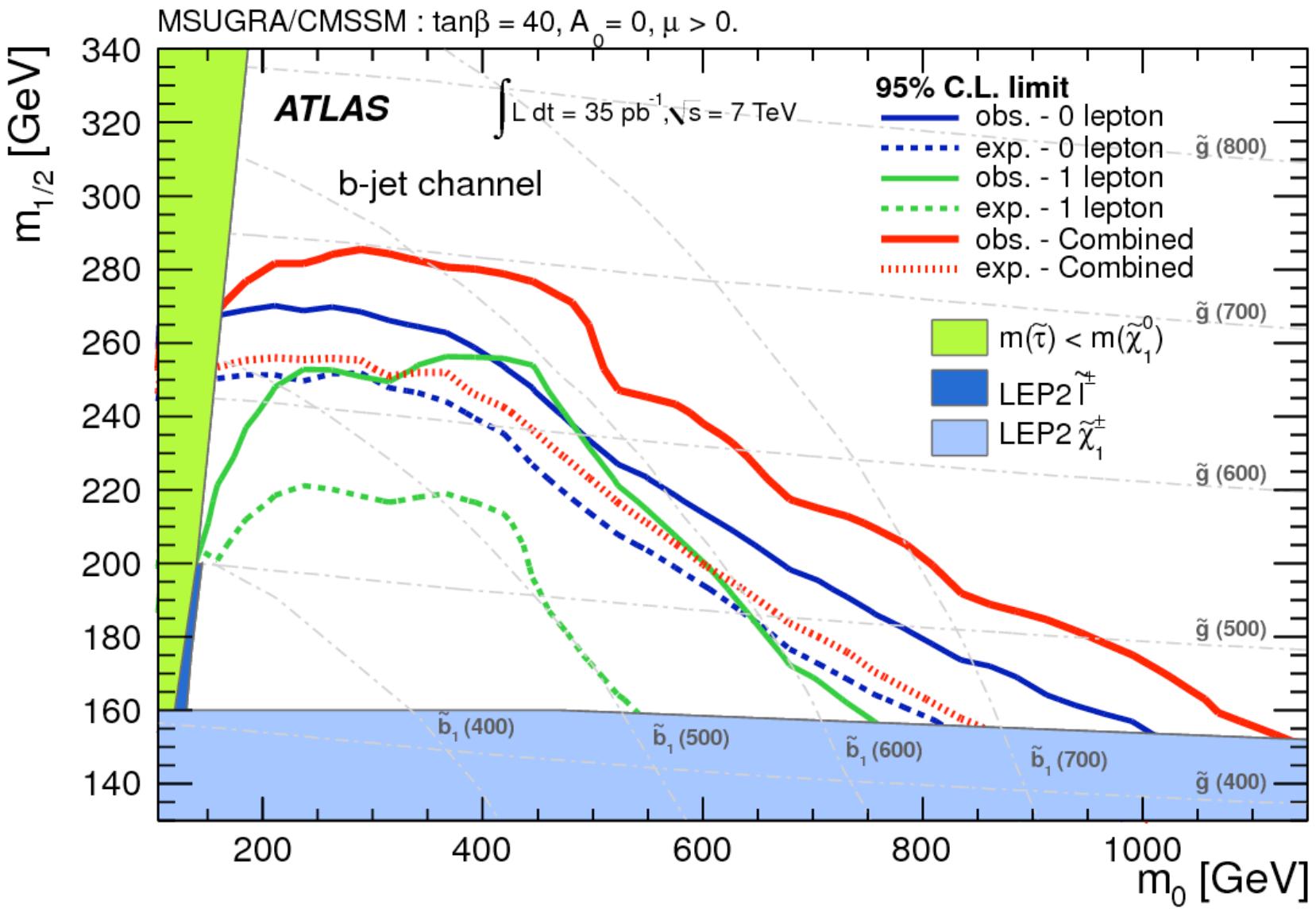
# SUSY: b-jets analysis



- Third generation squarks may have lower mass (higher cross-section) than 1st or 2nd generation.
- Search for events with ( $\geq 1$ b-jet) +  $E_T^{\text{miss}}$  + (0,  $\geq 1$ ) leptons.
- Dominant background for both selections is  $t\bar{t}$ .



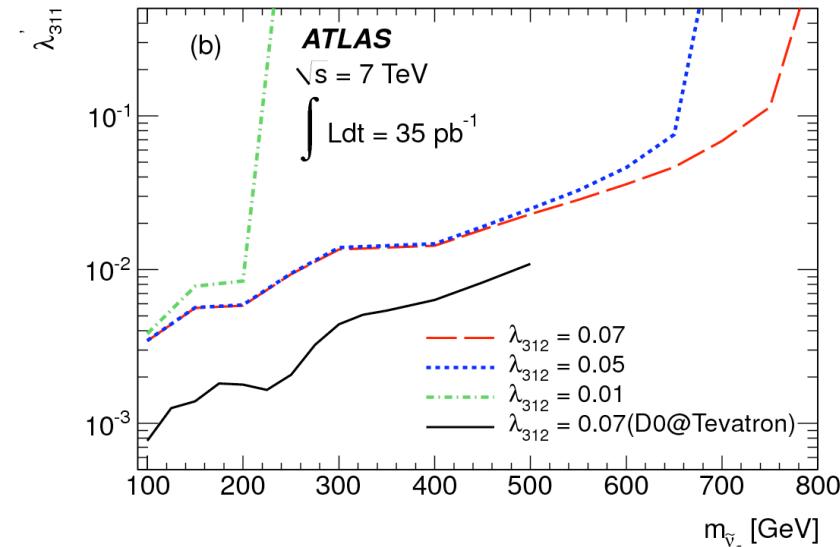
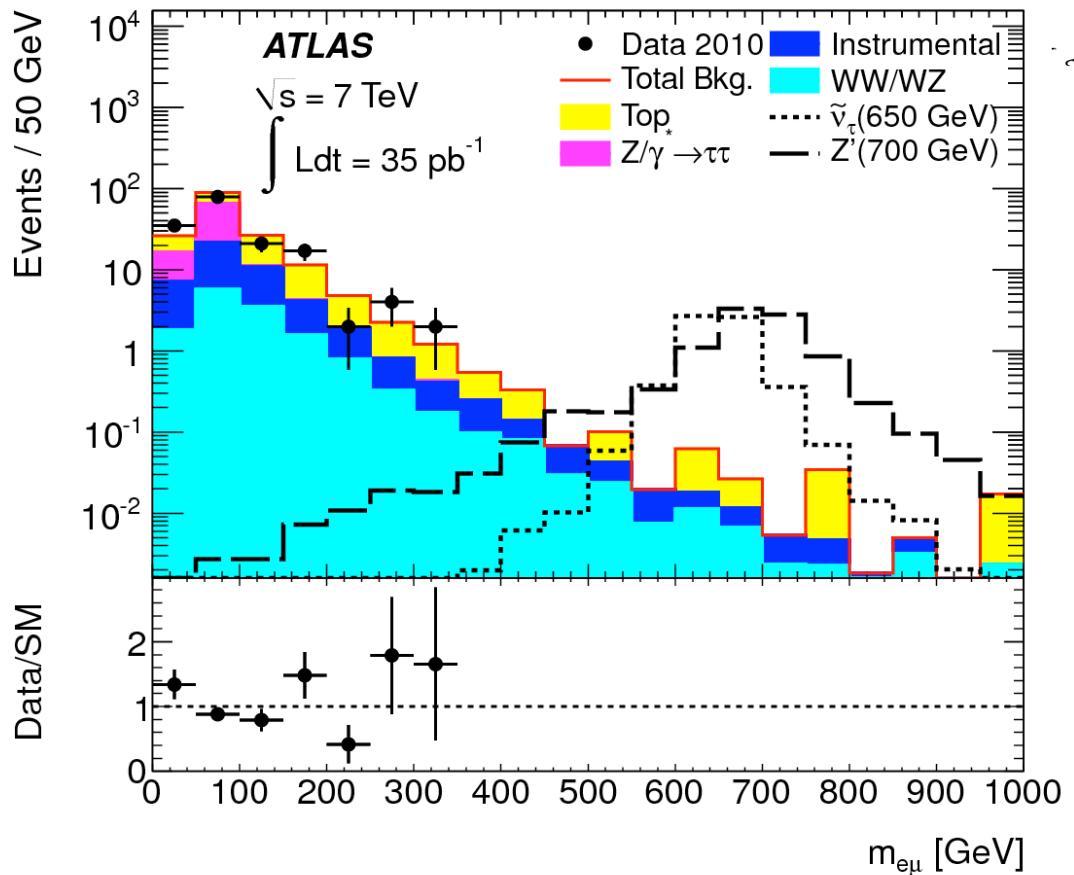
# SUSY: b-jets analysis



# SUSY: $e\mu$ resonance analysis



- Search for electron and muon of opposite charge.
  - $p_{T,\text{lepton}} > 20\text{GeV}$
- Determine background from fake leptons by solving system of linear equations to get fake probability for “tight” selection via a “loose” selection.



Excludes  $m_{\tilde{\nu}_\tau} < 750\text{MeV}$  given  
 RPV couplings  $\lambda'_{311} = 0.11$  and  
 $\lambda_{312} = 0.07$ .

# Exotica: Searches with Dijets

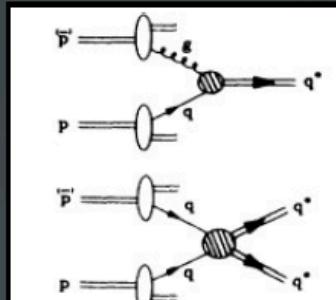


- $2 \rightarrow 2$  scattering well understood in SM (QCD)...any deviation from expected behavior of dijet processes would indicate new physics

- Excited quarks ( $q^*$ ): result of quark compositeness

**NEW!** Axigluons: would couple axially to quarks, arising from BSM extension of QCD including a chiral color gauge group

$$\mathcal{L}_{Aq\bar{q}} = g_{QCD} \bar{q} A_\mu^a \frac{\lambda^a}{2} \gamma^\mu \gamma_5 q$$



U. Baur, M. Spira, P.M Zerwas

**Quantum black holes:** Randall-Meade model with  $n=2$  to 7 extra dimensions

- Contact interactions: effective scale  $\Lambda$ :

$$\mathcal{L}_{qqqq}(\Lambda) = \frac{\xi g^2}{2\Lambda^2} \bar{\Psi}_q^L \gamma^\mu \Psi_q^L \bar{\Psi}_q^L \gamma_\mu \Psi_q^L$$

All new dijets results with  $36 \text{ pb}^{-1}$

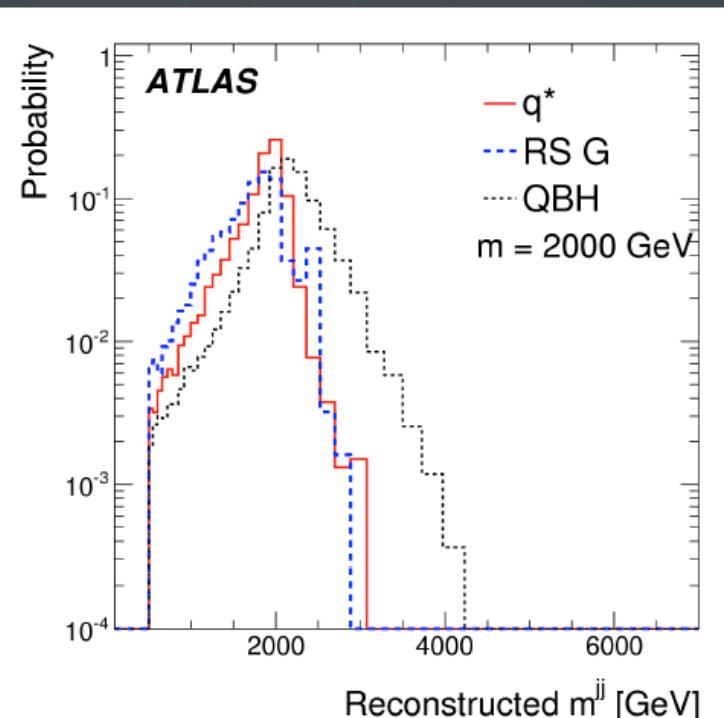
Previous ATLAS publications:

Dijet resonance:

Phys. Rev. Lett. 105, 161801 2010 ( $315 \text{ nb}^{-1}$ )

Quark Contact Interactions:

Phys. Lett. B694 327-345 2011 ( $3.1 \text{ pb}^{-1}$ )



# Exotica: Dijet Resonances

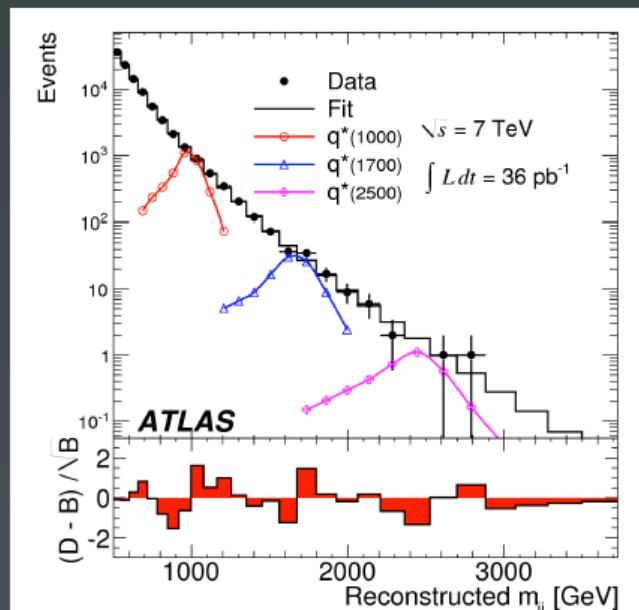
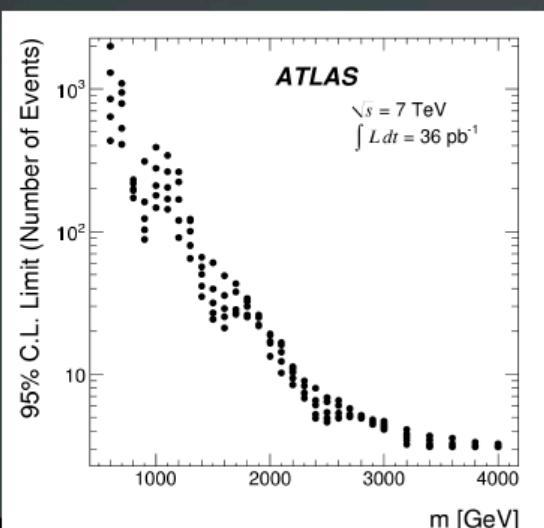


- Look at invariant mass of two jets:  $m_{jj} \equiv \sqrt{(E^{j_1} + E^{j_2})^2 - (\vec{p}^{j_1} + \vec{p}^{j_2})^2}$
- No evidence of a peak (p-value = 0.39 found with BumpHunter test)

**95% C.L LIMITS Observed (Expected)**

**Excited quarks ( $q^*$ ):       $M > 2.15$  (2.07) TeV**  
**Quantum Black Holes:     $M > 3.67$  (3.64) TeV**  
**Axigluons:                 $M > 2.10$  (2.01) TeV**

- Also can set limits on model-independent Gaussian resonances:



Using Gaussian with mean  $m$ , width  $\sigma$ :

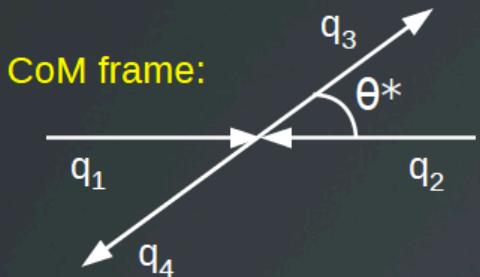
**Lower limits on  $N_{\text{obs}}$  (95% C.L.)**

Mean $m$ (GeV)	$\sigma/m$				
	0.03	0.05	0.07	0.10	0.15
1000	147	179	210	278	391
1500	24	27	32	40	60
2000	13	16	19	19	17
2500	4.6	4.9	5.4	6.4	6.9
3000	4.1	4.2	4.3	4.5	4.7

# Exotica: Angular distribution of Dijets



- Can gain sensitivity by looking at rapidity



$$y^* = \frac{1}{2} \ln \left( \frac{1+|\cos\theta^*|}{1-|\cos\theta^*|} \right)$$

$$y^* = \frac{1}{2}(y_1 - y_2)$$

- Observable variable:

$$\chi \equiv \exp(|y_1 - y_2|) = \exp(2|y^*|)$$

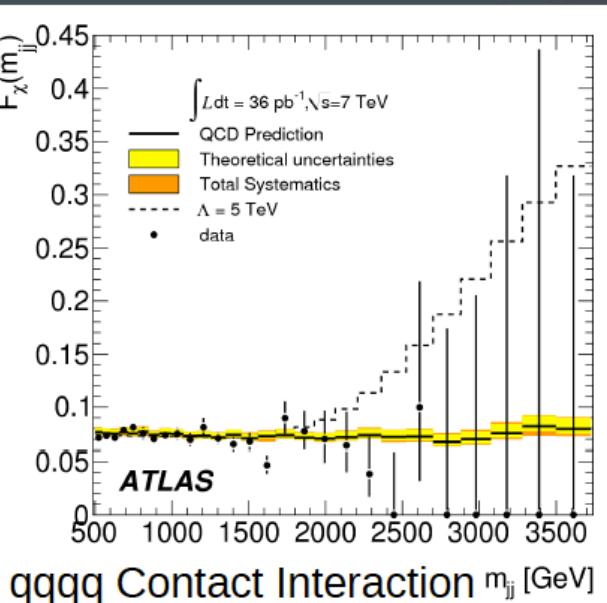
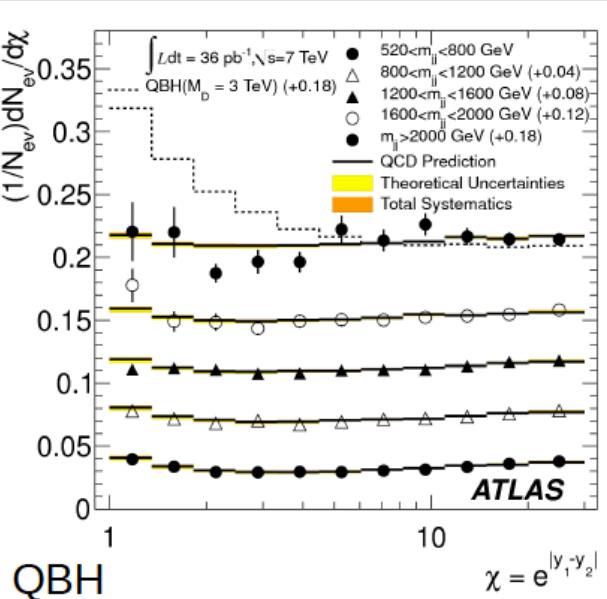


Also “chi fraction”:

$$F_\chi(m_{jj}) = \frac{N_{events}(|y^*| < 0.6)}{N_{events}(|y^*| < 1.7)}$$

Reduced sensitivity to absolute JES

- Well suited for contact interaction search (non-resonance search)



# Exotica: Dijet Limits



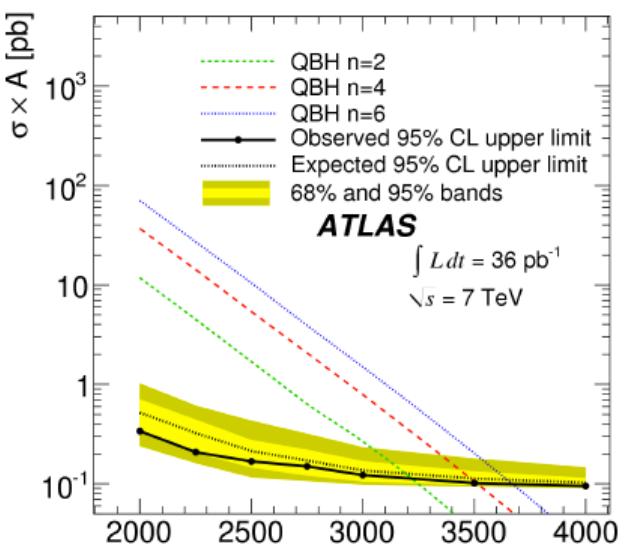
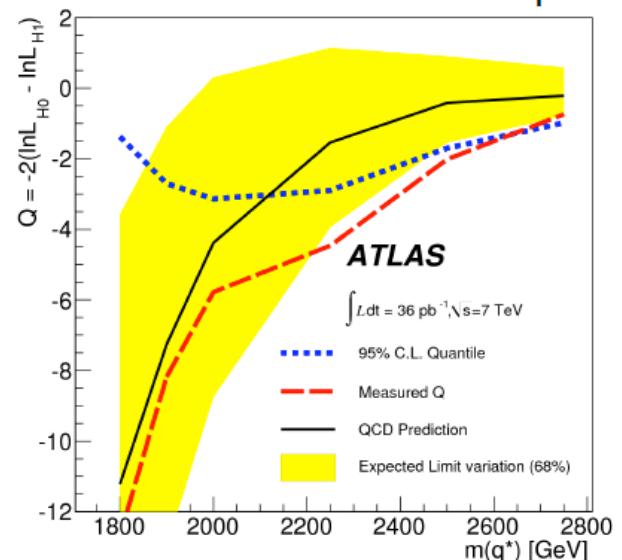
Model and Analysis Strategy	95% C.L. Limits (TeV)	
	Expected	Observed
Excited Quark $q^*$		
Resonance in $m_{jj}$	2.07	2.15
$F_\chi(m_{jj})$	<b>2.12</b>	<b>2.64</b>
Randall-Meade Quantum Black Hole for $n = 6$		
Resonance in $m_{jj}$	<b>3.64</b>	<b>3.67</b>
$F_\chi(m_{jj})$	3.49	3.78
$\theta_{np}$ Parameter for $m_{jj} > 2$ TeV	3.37	3.69
11-bin $\chi$ Distribution for $m_{jj} > 2$ TeV	3.36	3.49

## Axigluon

Resonance in $m_{jj}$	<b>2.01</b>	<b>2.10</b>
Contact Interaction $\Lambda$		
$F_\chi(m_{jj})$	<b>5.7</b>	<b>9.5</b>
$F_\chi$ for $m_{jj} > 2$ TeV	5.2	6.8
11-bin $\chi$ Distribution for $m_{jj} > 2$ TeV	5.4	6.6

## Previous Tevatron limits:

- Excited  $q^*$ :  $M > 0.870$  TeV (CDF 1.1  $\text{fb}^{-1}$ ) PRD79 112002, 2009
- Axigluons:  $M > 1.250$  TeV (CDF 1.1  $\text{fb}^{-1}$ ) PRD79 112002, 2009
- Contact Int:  $\Lambda > 2.9$  TeV (D0 0.7  $\text{fb}^{-1}$ ) PRL 103:191803, 2009

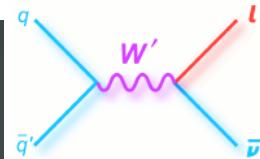




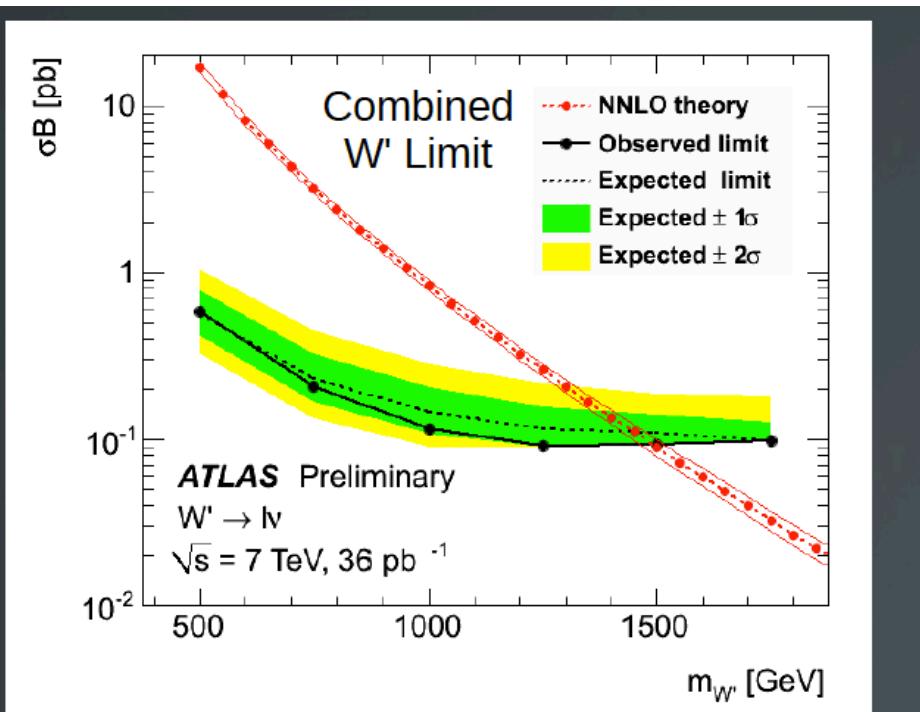
# Exotica: Extra Gauge Bosons ( $W'$ )



- $W' \rightarrow l\nu$ : Sequential Standard Model: Couplings same as SM bosons, width linearly scales with the mass
- Look for events in the transverse mass spectrum:

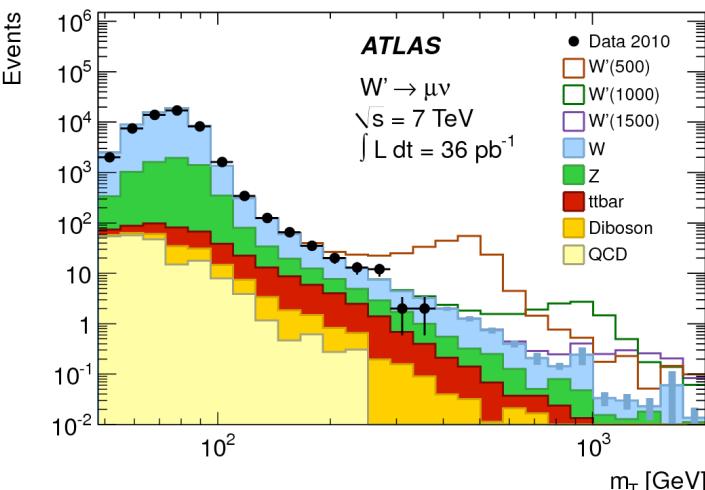
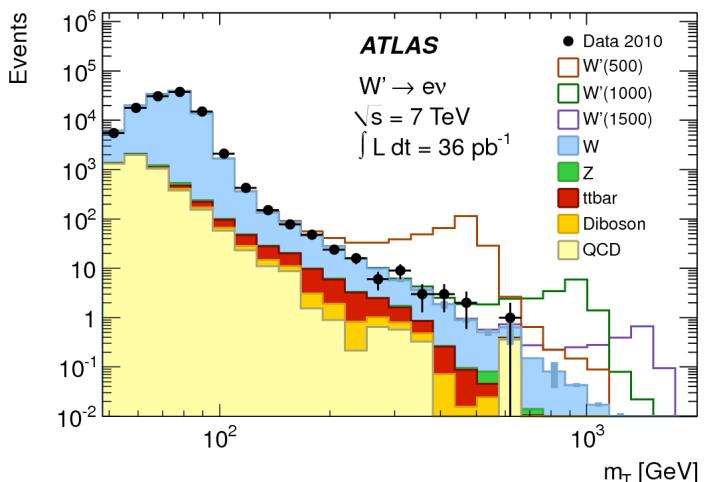


$$m_T = \sqrt{2 p_T^\ell E_T^{\text{miss}} (1 - \cos \varphi_{\ell\nu})}$$



**LIMIT 95% C.L. Observed (Expected):  
 $M_{W'} > 1.490$  (1.450) TeV**

Previous Tevatron Limit:  $M_{W'} > 1.100$  TeV  
(CDF public note 10303, 2010,  $5.3 \text{ fb}^{-1}$ )

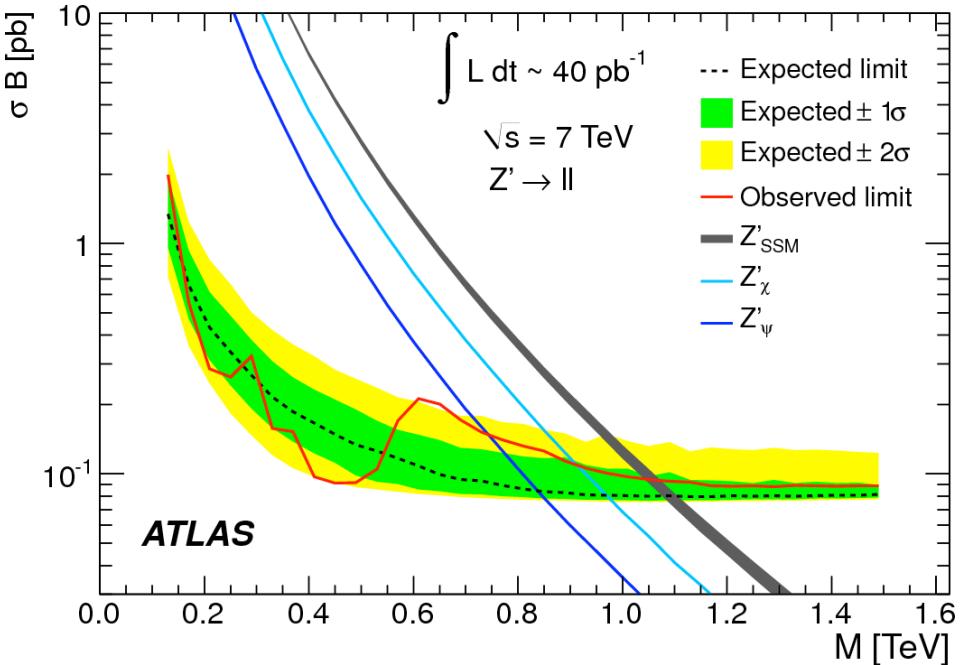




# Exotica: Extra Gauge Bosons ( $Z'$ )



- Dilepton resonances ( $Z'$ ), invariant mass spectrum
- $Z'$  SSM as well as string-theory-inspired E6 models



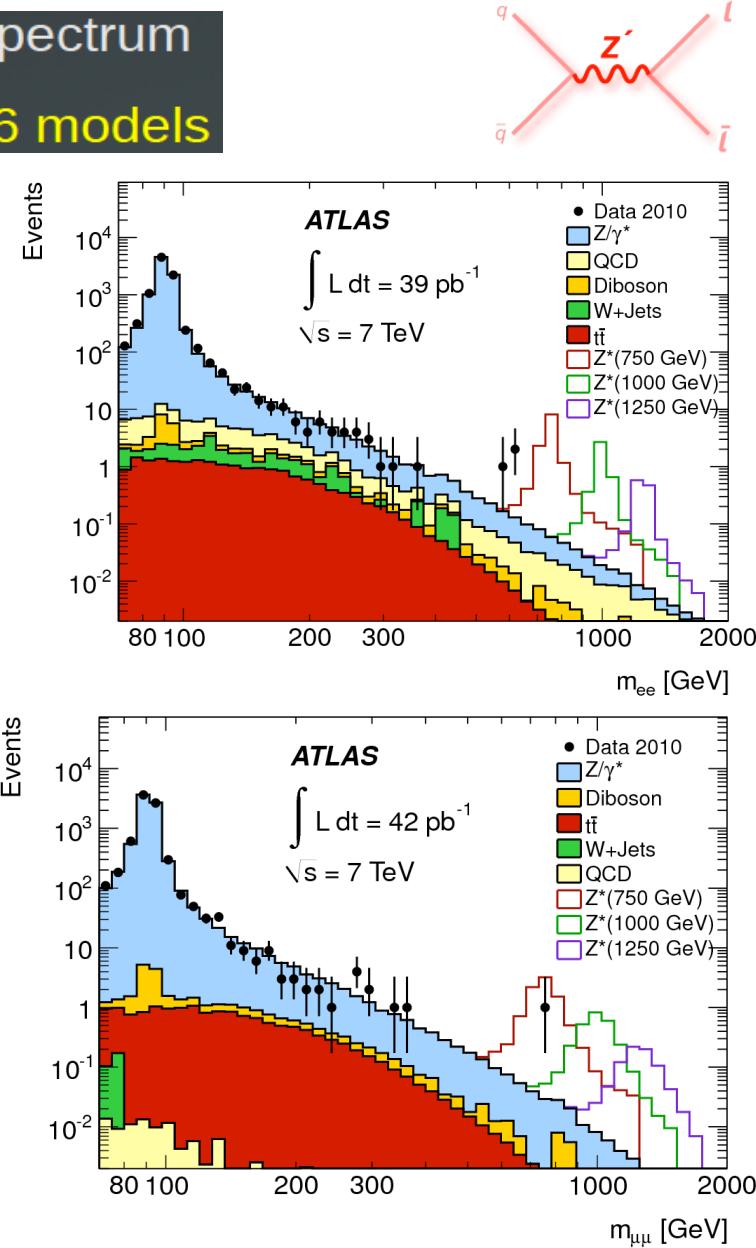
**LIMITS 95% C.L. Observed (Expected):**

$$M_{Z' \text{ SSM}} > 1.048 \text{ (1.088)} \text{ TeV}$$

E6: [TeV]	$Z'_\psi$	$Z'_N$	$Z'_\eta$	$Z'_I$	$Z'_S$	$Z'_\chi$
	0.738	0.763	0.771	0.842	0.871	0.900
	(0.837)	(0.860)	(0.866)	(0.922)	(0.945)	(0.965)

Previous Tevatron Limit:  $M_{Z' \text{ SSM}} > 1.071 \text{ TeV}$

(CDF 4.6 fb $^{-1}$  arXiv:1101.4578, 2011)





# Exotica: Searches with Di-Photons

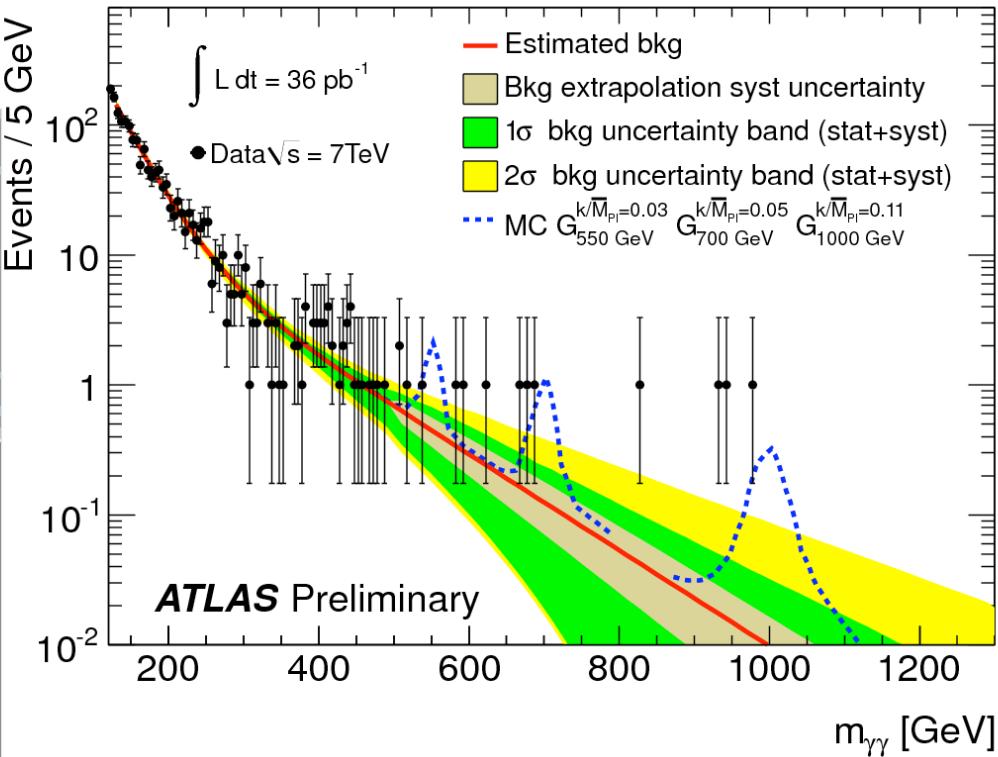
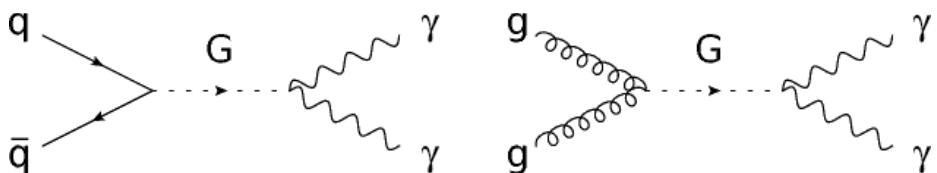
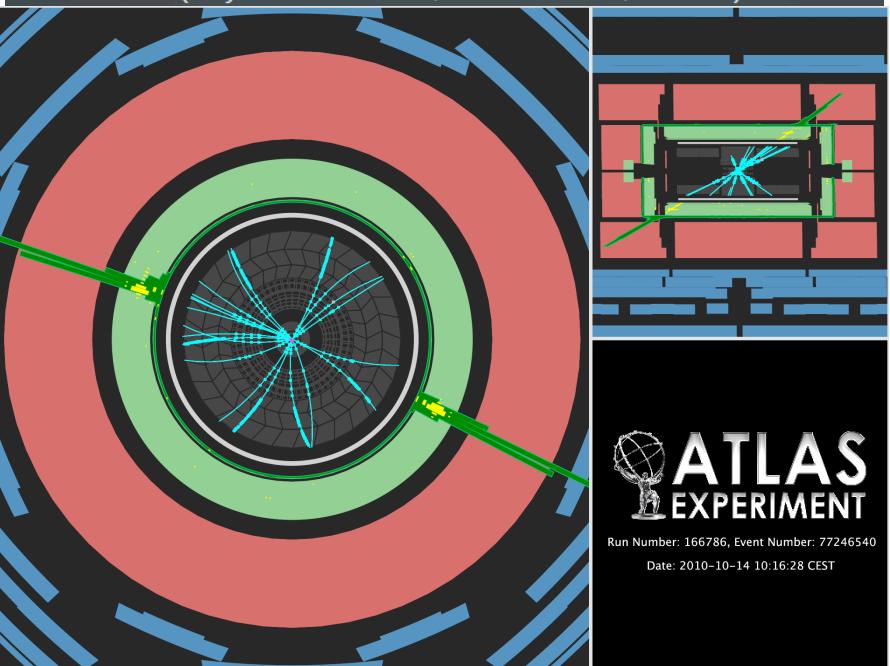


- RS Gravitons ( $36 \text{ pb}^{-1}$ ) **NEW!**
- Plank scale  $\leftrightarrow$  TeV scale  $\Lambda_\pi = \bar{M}_{\text{Pl}} \exp(-k\pi r_c)$
- Predict a spin 2 graviton as lightest state of Kaluza-Klein (KK) tower with mass  $M_G$
- $R$  = compactification radius,  $k$  = curvature, coupling defined by  $k/M_{\text{PL}}$

**LIMITS  $M_G > 545 \text{ GeV}$  ( $k/M_{\text{PL}} = 0.02$ )**

**95% C.L.:  $M_G > 920 \text{ GeV}$  ( $k/M_{\text{PL}} = 0.1$ )**

Previous Tevatron limit (D0):  $M_G > 1.050 \text{ GeV}$  ( $k/M_{\text{PL}}=0.1$ )  
(Phys Rev Lett 104, 241802 2010,  $5.4 \text{ fb}^{-1}$ )





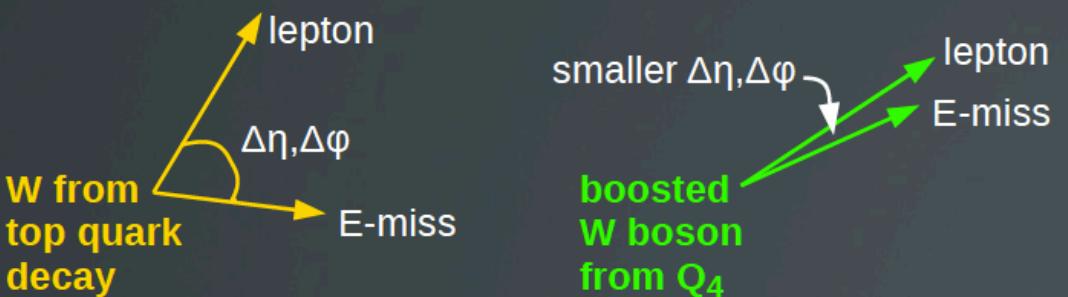
# Exotica: Leptons AND Jets!



- 4<sup>th</sup> generation chiral quarks: 2 jets, 2 leptons,  $E_T\text{miss}$

$$Q_4 \bar{Q}_4 \rightarrow W^+ q W^- \bar{q} \rightarrow \ell^+ \nu q \ell^- \nu \bar{q}$$

- $M_{\text{collinear}}$  vs  $H_T$  can be used as a discriminant against dominant ttbar background
  - $H_T$  = scalar sum of  $E_T$  from leptons, jets and  $E_T\text{miss}$
  - “Collinear Mass”: Find best  $\Delta\eta, \Delta\phi$  for each lv pair to minimize difference in the two  $Q_4$  reconstructed masses ( $M_{\text{collinear}}$ )

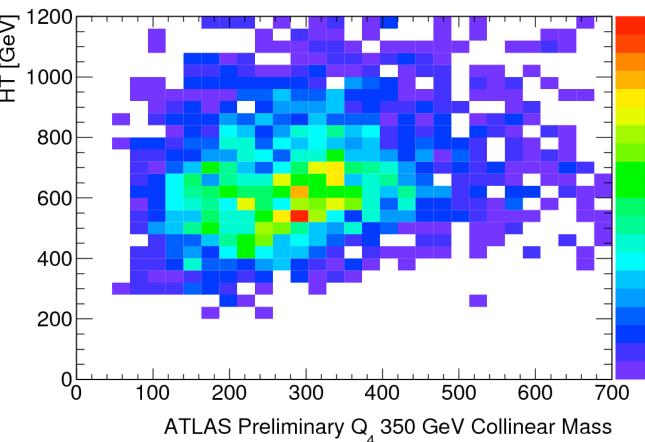
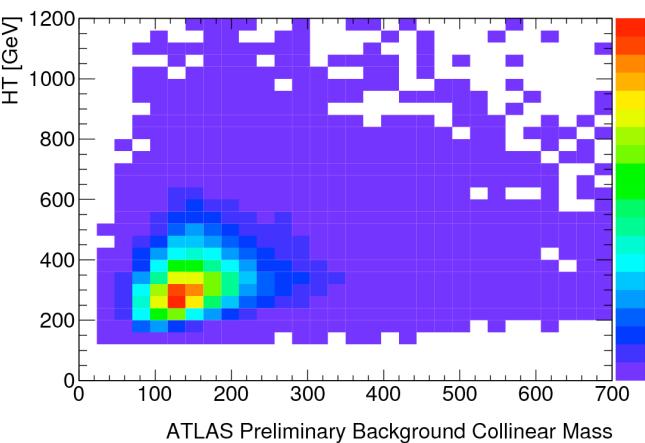
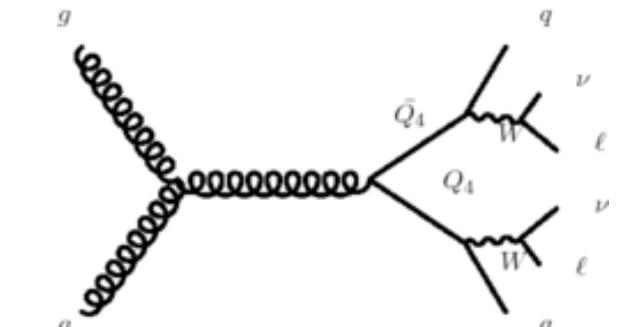


**LIMIT 95% C.L. Obs (Exp):**  
 $M_{Q4} > 270$  (284) GeV

Limit with 5.6 fb<sup>-1</sup> (CDF):  $M_{u4} > 356$  GeV

Limit with 4.8 fb<sup>-1</sup> (CDF):  $M_{d4} > 372$  GeV

(CDFNote CDF/PUB/TOP/PUBLIC/10110,  
arXiv:1101.5728)

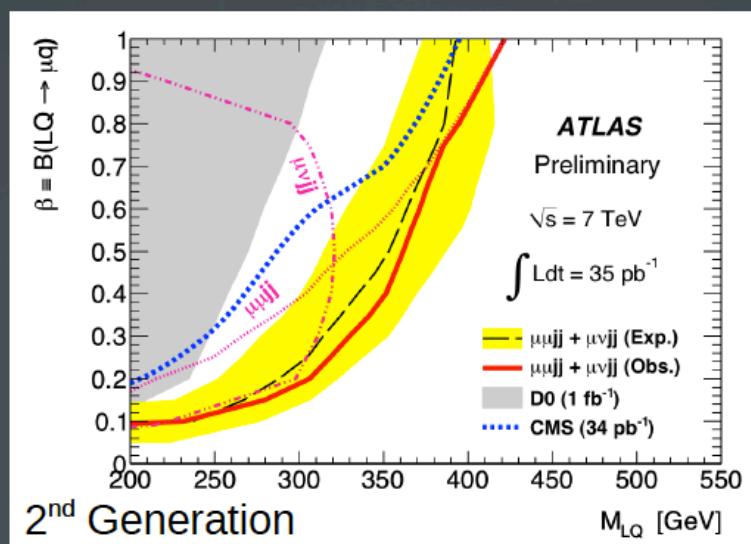
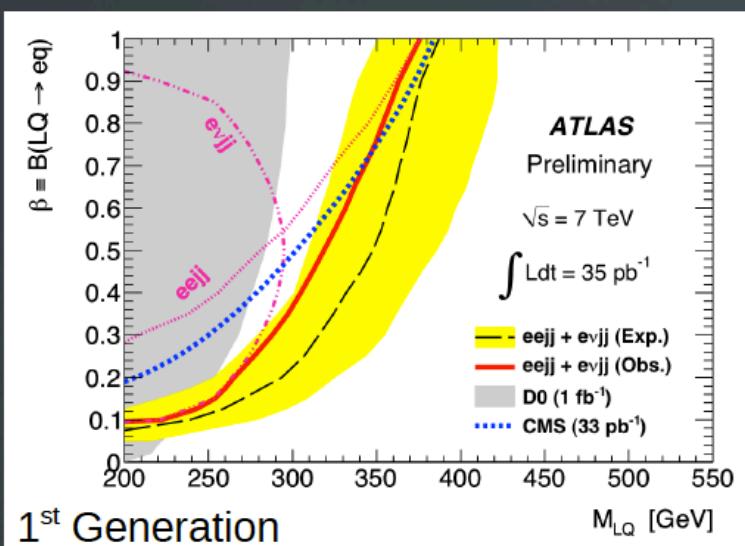
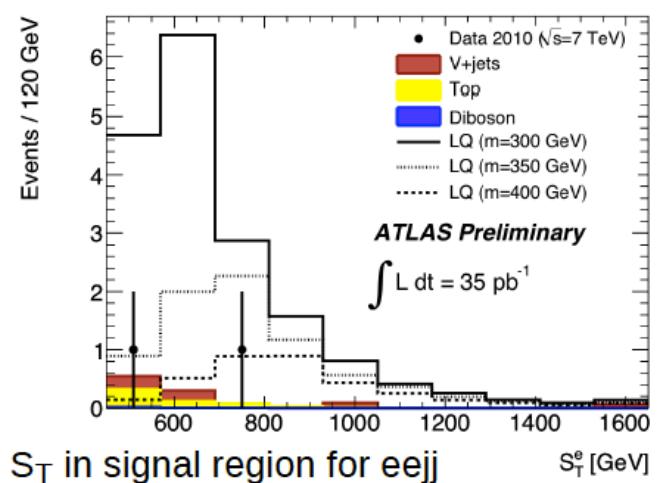


First dilepton  
 $u_4$  search,  
and first search  
at the LHC!



# Exotica: Leptoquarks

- Possess both lepton and quantum numbers
  - Pair produced...search for charged lepton ( $q\bar{q}ll$ ) or neutrino ( $q\bar{q}\nu l$ ) daughter
  - High inv mass of lepton-jet pair has little bkgnd
  - Also look at  $M_T$  and sum of transverse energy:
- $$M_{LQ}^T = \sqrt{2p_T^j E_T^{\text{miss}}(1 - \cos \phi^j)}$$
- $$S_T^\ell = p_T^{\ell_1} + p_T^{\ell_2} + p_T^{j_1} + p_T^{j_2}$$
- $\beta = \text{BF}$  for single leptoquark to decay to  $l^\pm q$



95% C.L. LIMITS Observed (Expected) [GeV]

1<sup>st</sup> Generation:  $M > 376$  (387) ]  $\beta=1.0$   
 2<sup>nd</sup> Generation:  $M > 422$  (393) ]  $\beta=1.0$

$M > 319$  (348) ]  $\beta=0.5$   
 $M > 362$  (353) ]  $\beta=0.5$

Limits with 1  $\text{fb}^{-1}$  (D0)  
 (Phys Lett B 671 224, 2009)



# Exotica Summary

Mass limits (95% C.L.) [TeV]:

Tevatron <b>ATLAS</b>				Tevatron <b>ATLAS</b>			
Dijets	Excited quarks ( $q^*$ )	0.87	<b>2.64*</b>	Dileptons	Z' SSM (e+μ)	1.071	1.048
	QBHs	-	<b>3.67*</b>		E6 $Z'_X$ (e+μ)	0.930	0.900
	Axigluons	1.25	<b>2.10*</b>		E6 $Z'_\Psi$ (e+μ)	0.917	0.738
	Contact Int. $\Lambda$ qqqq	2.9	<b>9.5*</b>		E6 $Z'_N$ (e+μ)	0.900	0.763
Lepton +MET	W' SSM (e+μ)	1.100	<b>1.490</b>		E6 $Z'_\eta$ (e+μ)	0.938	0.771
Leptons +MET+ jets	4 <sup>th</sup> gen quark Q <sub>u4</sub>	0.356	0.270		E6 $Z'_l$ (e+μ)	0.817	<b>0.842</b>
	1 <sup>st</sup> gen LQ ( $\beta=1.0$ )	0.299	<b>0.376</b>		E6 $Z'_s$ (e+μ)	0.858	<b>0.871</b>
	2 <sup>nd</sup> gen LQ ( $\beta=1.0$ )	0.316	<b>0.422</b>	γγ	RS Graviton	1.050	0.920
* world's best limit				γγ+MET	UED (1/R)	0.477	<b>0.728*</b>

With very little data, we're able to push the reach to the TeV scale and set world's best limits!

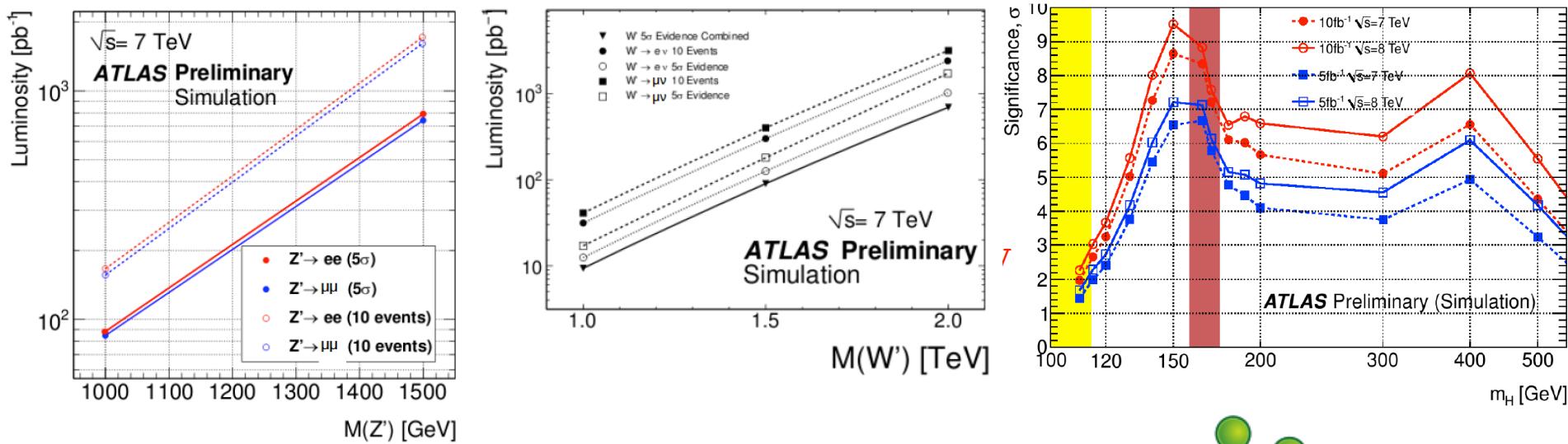
# Conclusions and Outlook



We've only recently set *sail for the Terascale*, but interesting, high-quality results have come very rapidly from both experiments

- excellent LHC accelerator and detector performance
- analyses have benefited greatly from the Tevatron experience

Expect LHC to deliver  $1\text{-}3 \text{ fb}^{-1}$  this year and more by the end of 2012



We've got a wild and exciting voyage just beginning, so buckle up and stay tuned!

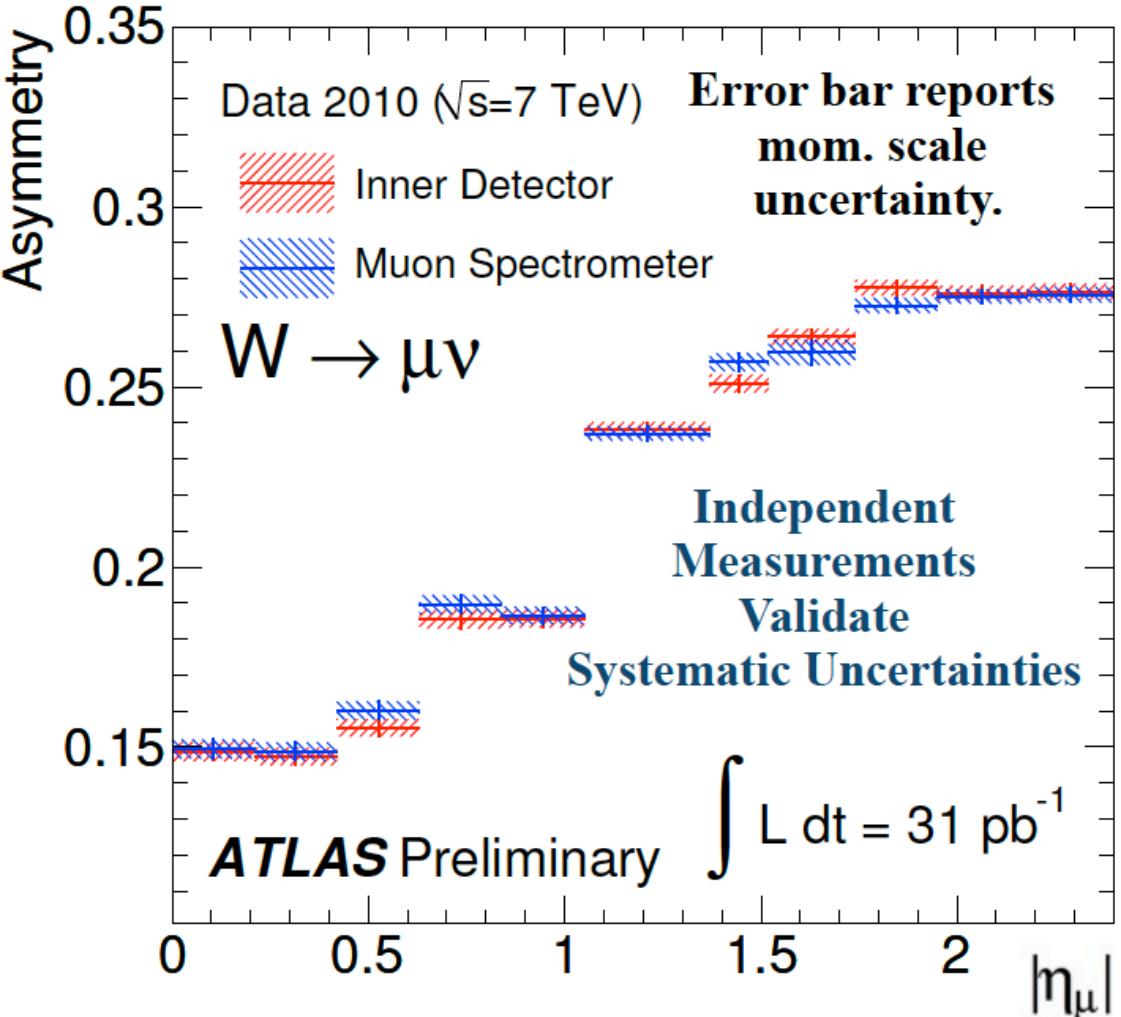




# Extras



# W Charge Asymmetry

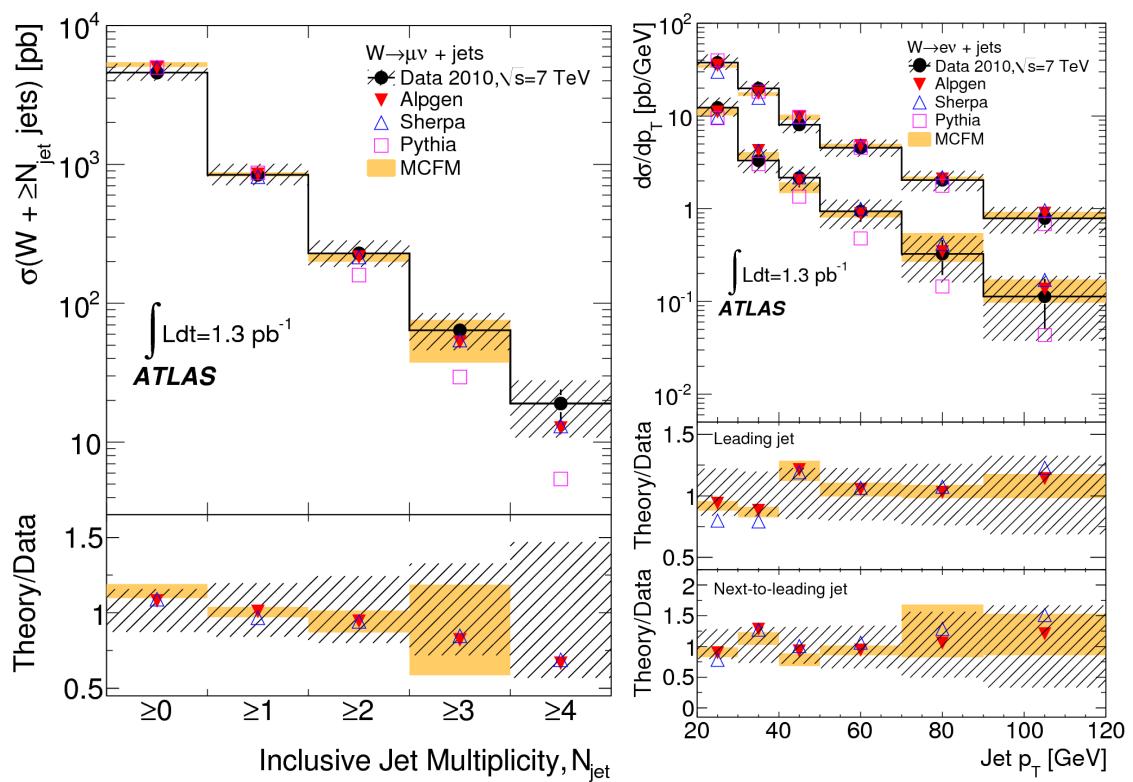


Current Experimental Uncertainties Already Comparable to those of Global Fits.

# W + jets



- Atlas results with  $1.3\text{pb}^{-1}$  for W+jets
- Similar results between muon and electron channels
- MCFM has QED and soft QCD corrections applied for comparison with data.
- **NLO calculations (MCFM, 0-2 jets) are in good agreement with the measured cross-sections**



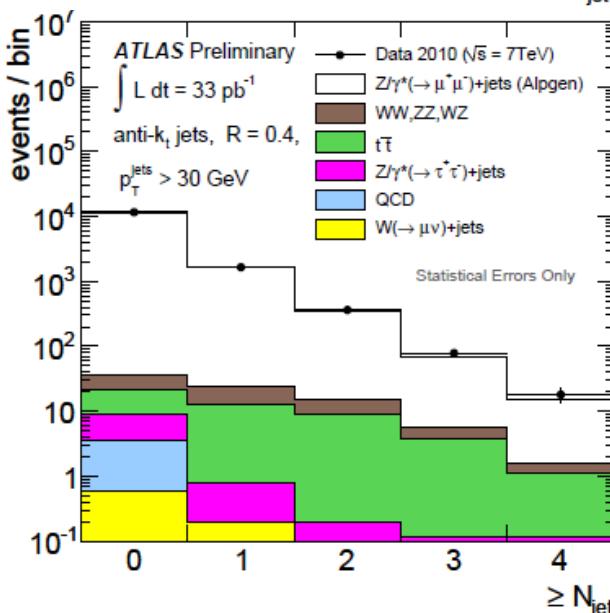
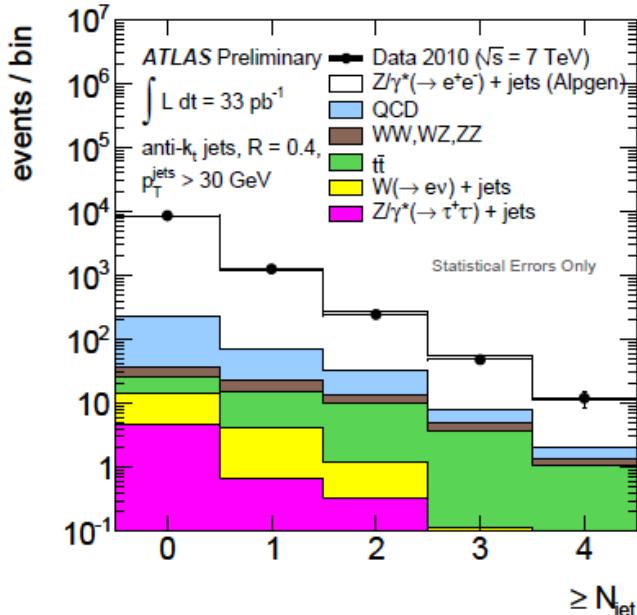


- Vector Boson+jets cross section stringent **test of pQCD**
  - choice of scales, parton showering,...
- Important **background for SM and beyond SM processes**

- **Jet selection:**
  - Anti-Kt jets
  - $P_T > 30 \text{ GeV}$
  - Pile-up jet veto:
    - Only trk from best PV considered

$$JVF = \frac{\sum_{\text{trk} \in \text{jet}} P_T}{\sum_{\text{all trk}} P_T} > 0.75$$

- **Background**
  - Increase with jet multiplicity
  - QCD background
    - Small in muon channel
    - Data driven estimate in electron channel (2% - 7%)
  - EW background
    - Mainly top at large jet multiplicity (0.1% - 6%)



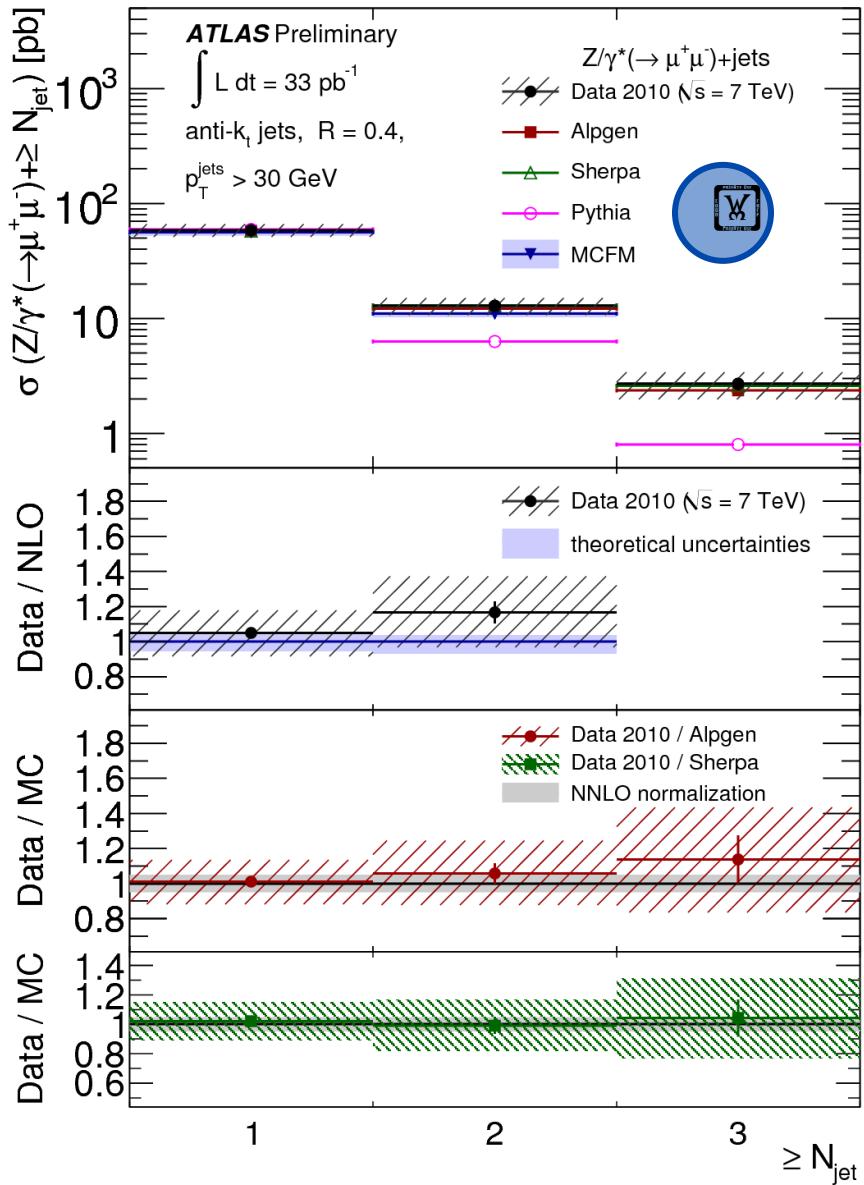
# Z + jets



- Unfolding detector effects
  - Bin-by-Bin corrections

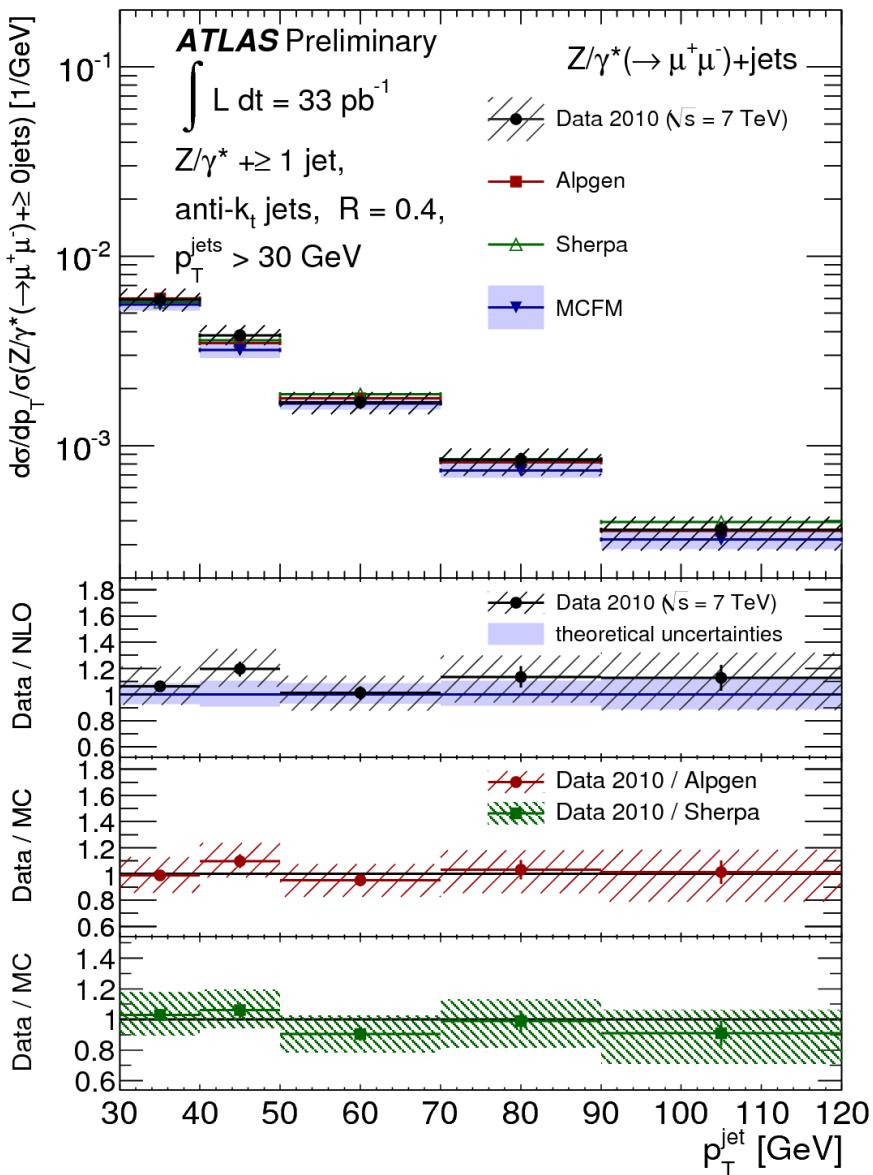
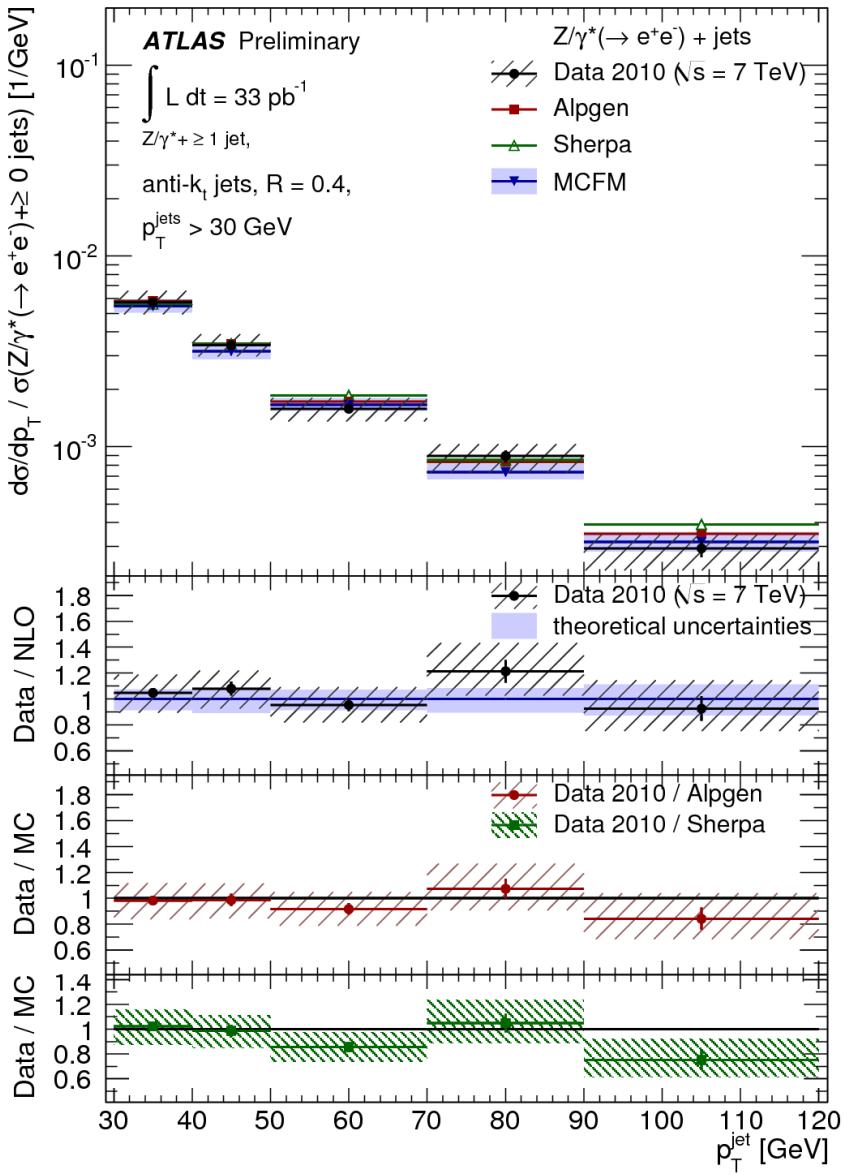
$$\frac{d\sigma}{d\alpha} = \left( \frac{N_{DATA} - N_{BKG}}{L_{int}} \right) * U_{MC}(\alpha)$$

- Nominal: Alpgen
- Systematics: Sherpa
- Systematics uncertainties dominated by JES, JER and JVF veto
- **NLO predictions and generators are in agreement with measured cross sections**
  - Except Pythia which does not reproduce the data at high jet multiplicity



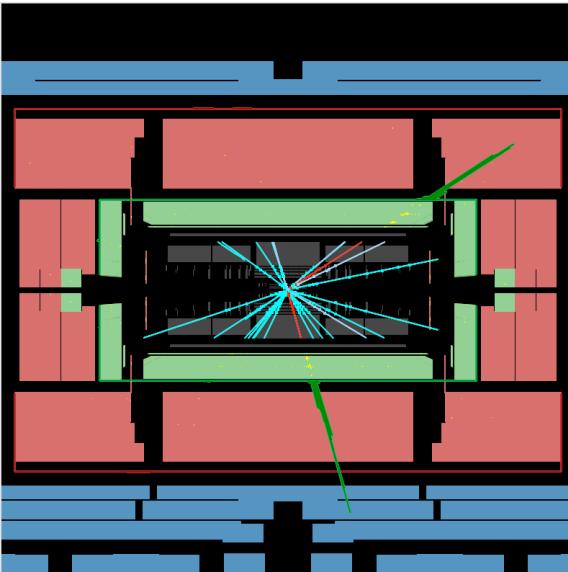
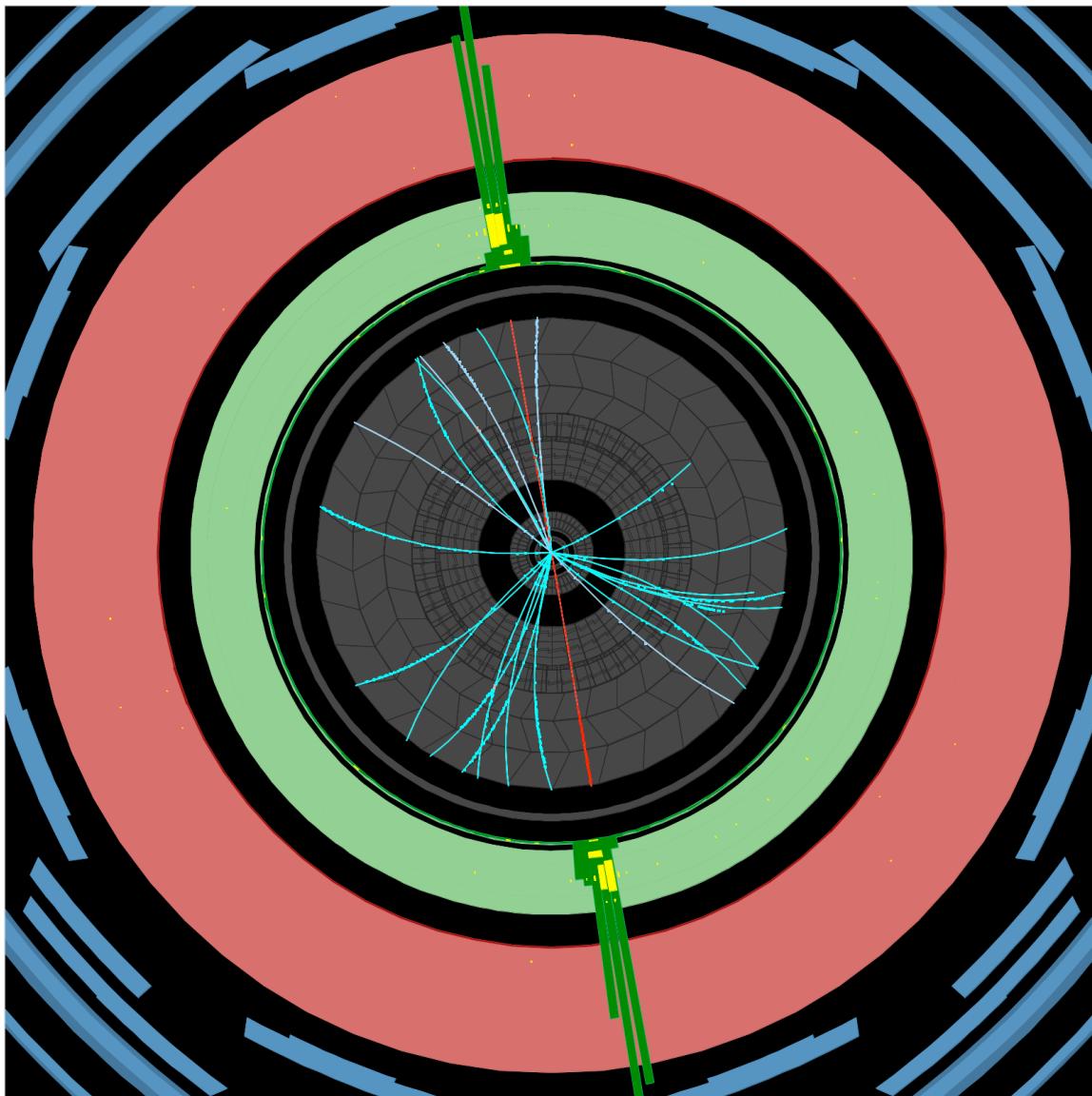


# Z + jets





# Highest Mass Dielectron Event



**ATLAS**  
EXPERIMENT

Run Number: 167576, Event Number: 22999252

Date: 2010-10-24 12:22:12 CEST



## ► Search for anomalous $E_T^{\text{miss}}$ in $t\bar{t}$ (l+jets) events

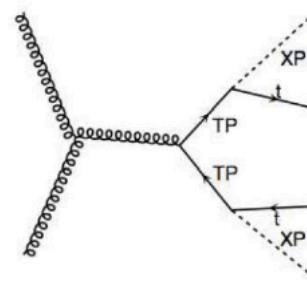
### – benchmark: $T\bar{T}$ pair, $T \rightarrow tA_0$

- $A_0$  dark matter candidate
- Enhanced cross-section due to spin states

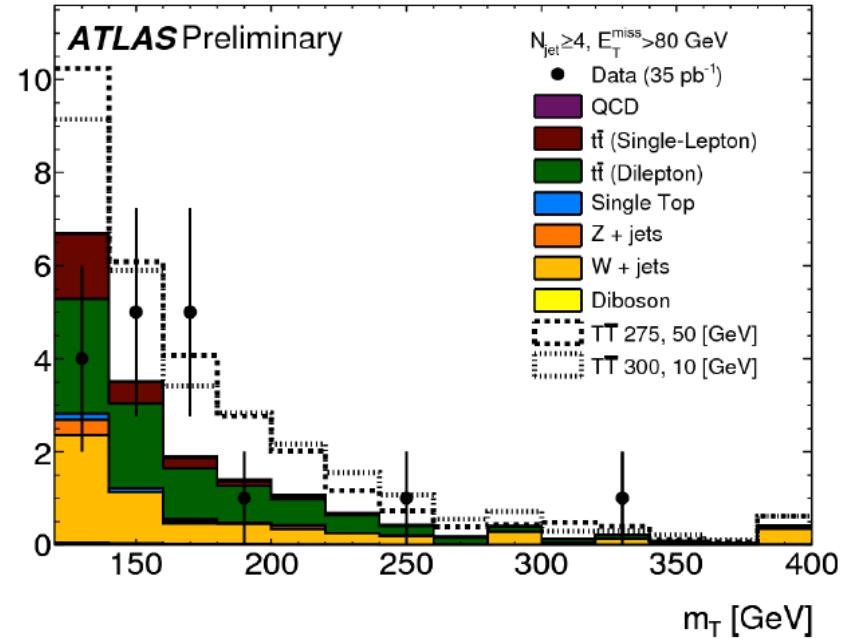
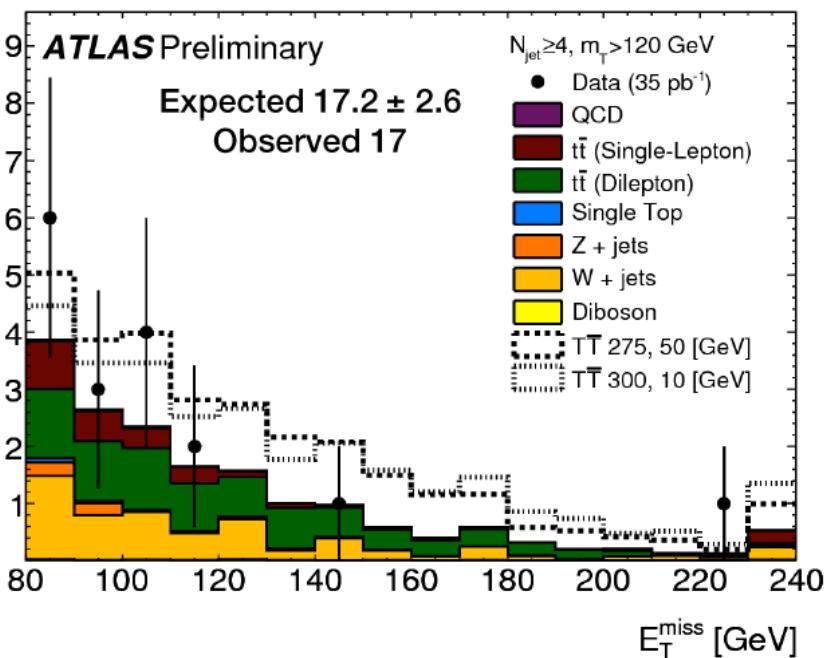
### – Signal region:

- $E_T^{\text{miss}} > 80 \text{ GeV}$ ,  $m_T > 120 \text{ GeV}$ ; dilepton veto:  $p_T > 15 \text{ GeV}$ , tracks, loose electrons

### – Exclude $m(T) < 275(300) \text{ GeV}$ for $m(A_0) < 50(10) \text{ GeV}$



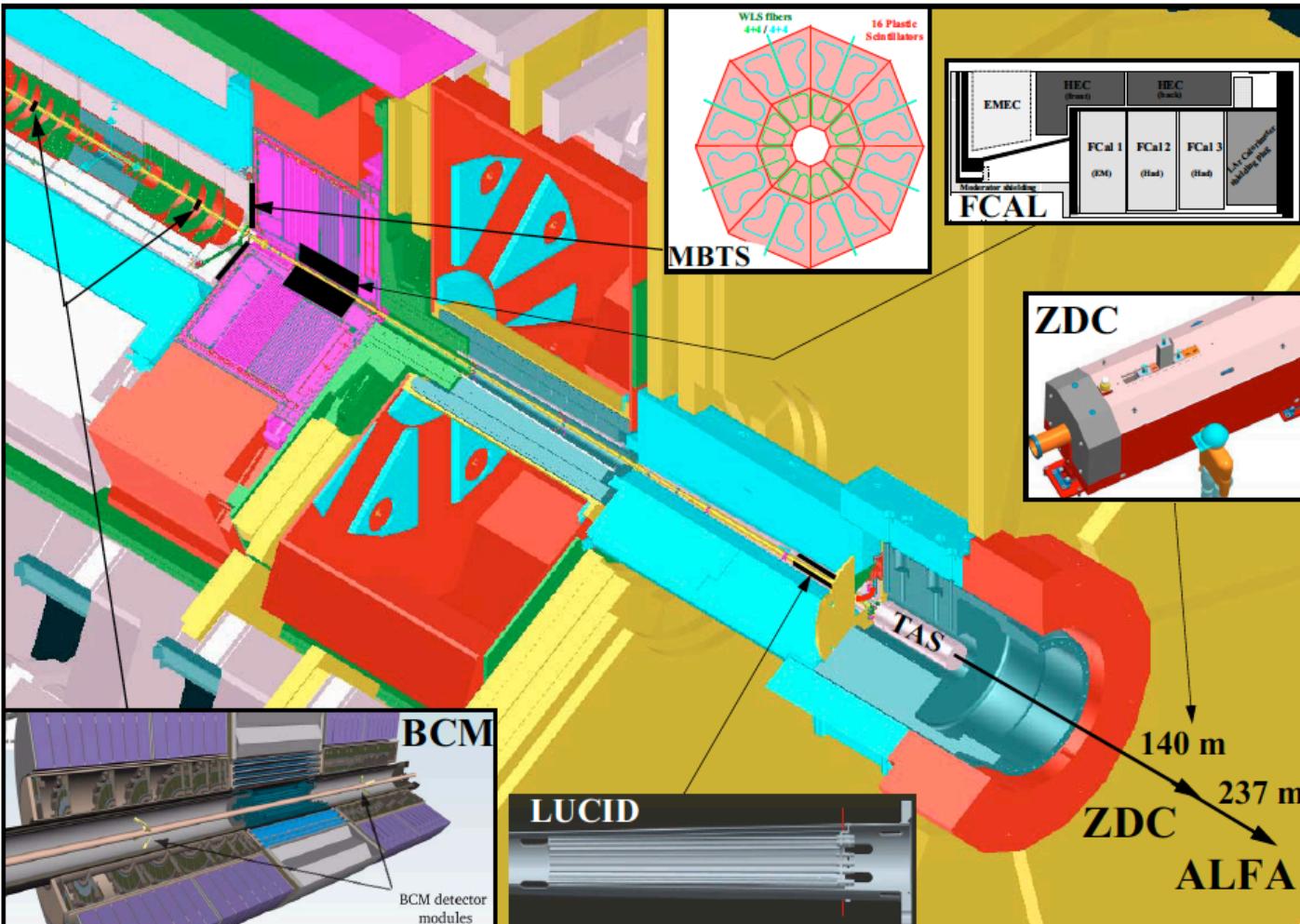
Alwall, Feng, Kumar *et al.* (2010)  
Berger, Cao (2009)





# Luminosity Determination

## Online



## Offline

**VTX:** Events with primary vertex

**Tracks:** Events with vertex + tracks

**MBTS-timing:** Events with MBTS signals (A and C in time)

**LAr-timing:** Events with LAr signals (A and C in time)

**W & Z counting**

# PhenoGrid2 SUSY Parameters



- 24-parameter MSSM framework:

$m_A = 100\text{GeV}$ ,  $\mu = 1.5 \times \min(m_{gl}, m_q)$ ,  $\tan \beta = 4$ ,  $A_t = \mu / \tan \beta$ ,  $A_b = A_l = \mu \tan \beta$

Common squark, slepton masses for first 2 generations,  
3rd generation at higher mass.

- “Compressed spectrum” (CS): soft particles
- “Light neutralino” (LN): harder kinematics

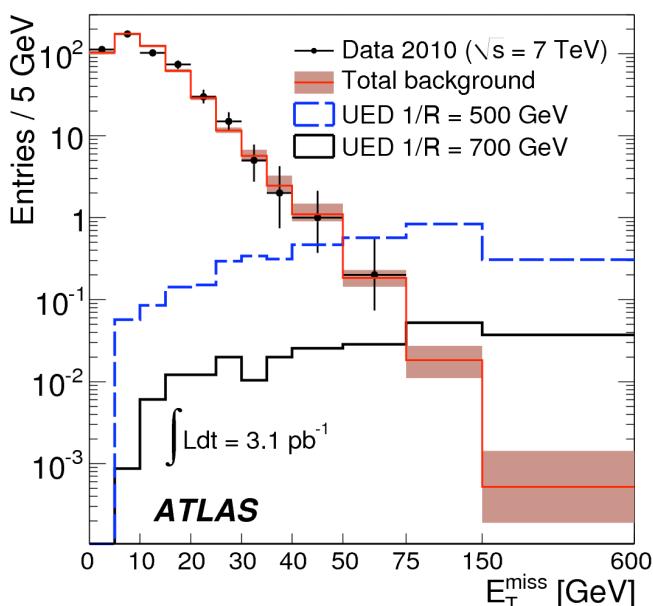
# Exotica: Searches with Di-Photons



- Universal Extra Dimensions ( $3.1 \text{ pb}^{-1}$ )
- Masses of states in KK tower of gravitons separated by  $1/r$  ...lightest KK particle: KK photon
- $\gamma^* \rightarrow \gamma + G$  (x2 per event)  
→ observe:  $\gamma\gamma + E_T\text{miss}$  (+ other SM)
- Signal in  $E_T\text{miss} > 75 \text{ GeV}$ , observe 0 events

**LIMIT:  $1/R > 728 \text{ GeV (95\% C.L.)}$**

Previous Tevatron limit (D0):  $1/R > 477 \text{ GeV}$  (PRL 105, 221802, 2010,  $6.3 \text{ fb}^{-1}$ )



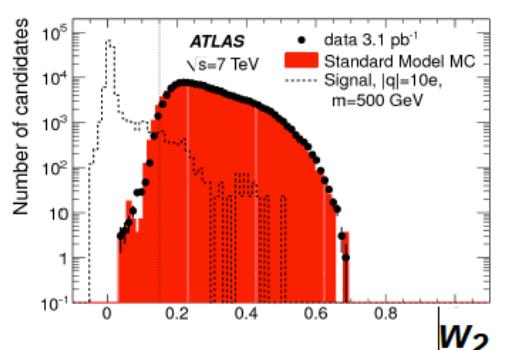
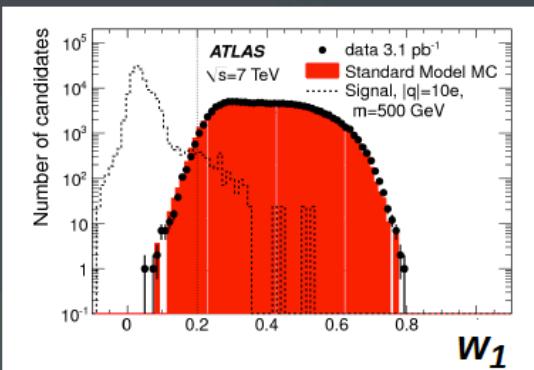
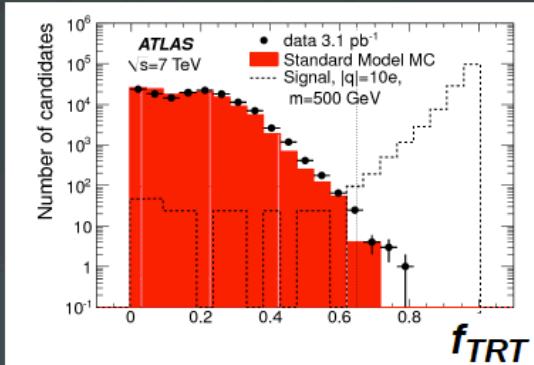
# Exotica: Long-lived Highly Ionizing Particles (HIPs)



- Q-balls, stable micro blackholes, magnetic monopoles, dyons  $3.1 \text{ pb}^{-1}$
- Non-relativistically move through detector
- Charge ( $q$ )  $\gg$  elementary charge ( $e$ )
- The presence of HIP can be found by measuring:
  - $f_{TRT}$  – Fraction of TRT hits on the track which pass high-threshold (high-ionization hits)
  - $w_1, w_2$  – Fraction of energy deposited outside 3 most energetic cells first and second layers of the EM calorimeter
- Pair production assuming DY mechanism

**Limits on production cross section: (95% C.L.)**

$m \text{ [GeV]}$	$ q  = 6e$	$ q  = 10e$	$ q  = 17e$
200	11.5	5.9	9.1
500	7.2	4.3	5.3
1000	9.3	3.4	4.3



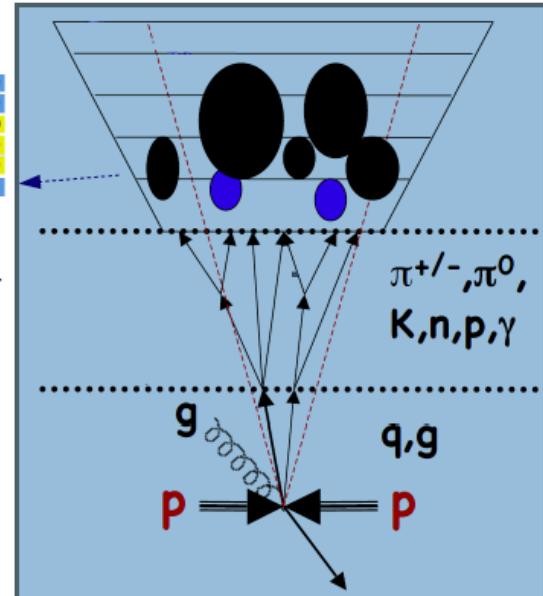
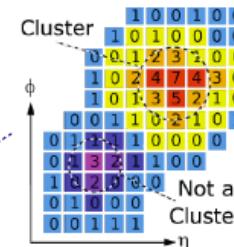
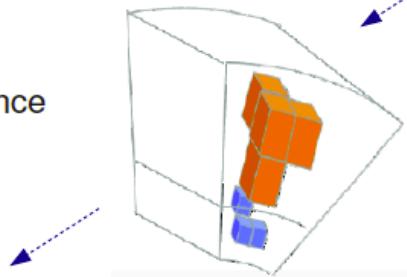
# Jet energy calibration in ATLAS

## Starting point:

- ▶ calorimeter cells calibrated to electromagnetic scale
    - 190.000 cells (with volume of single cell  $2\text{cl} \div 300 \text{ MaB}$ )

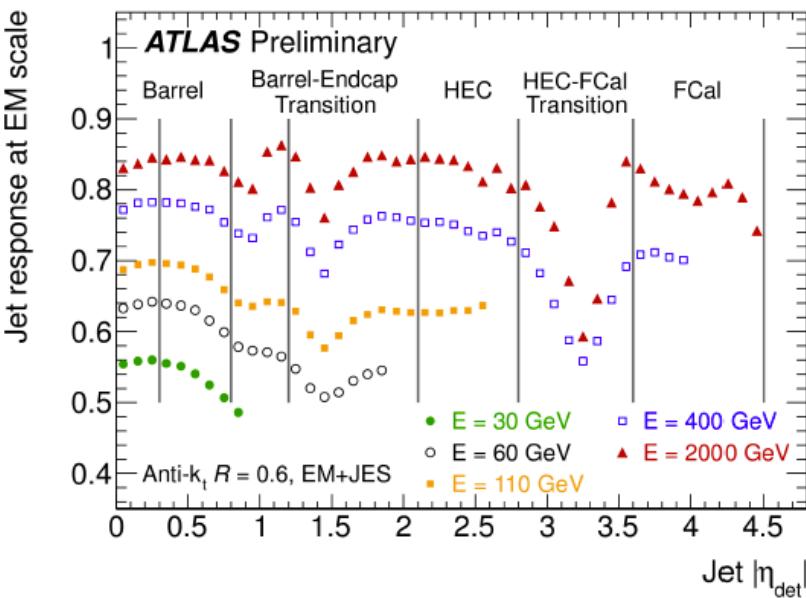
## Input to jet reconstruction

- 3D Topological clusters
    - uses nearest neighbor energy significance to localize showers in the calorimeter
    - efficient noise suppression



## Jet reconstruction

- Jets are reconstructed using the anti- $\text{kt}$  algorithm with size parameter  $R$  set at 0.6 (0.4).



## Jet calibration

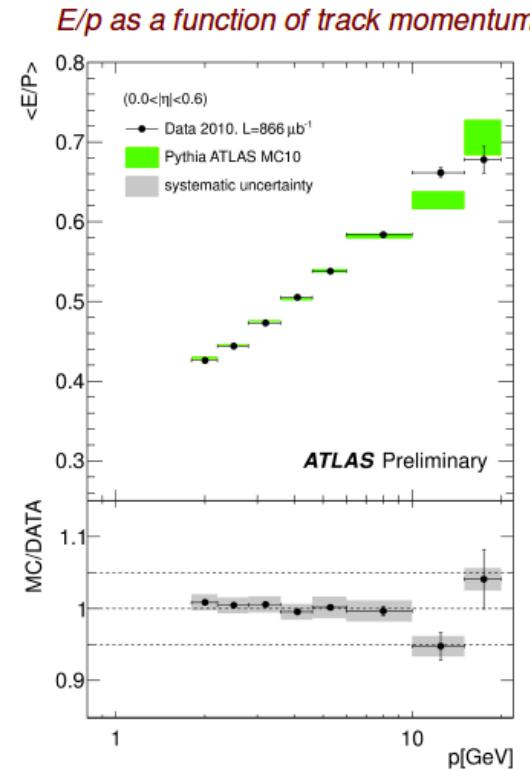
- Energy and momentum of a jet measured in the calorimeter are corrected using kinematics of a Monte Carlo truth jet as reference
    - for non-compensation, energy losses in dead material, shower leakage
    - inclusive QCD events from pp using PYTHIA 6.4.24
  - EM+JES schema - simple default Monte Carlo based calibration
    - ( $\eta$ ,  $p_T$ ) dependent correction factor  $E_{truth}/E_{calo}^{EM}$

# Default jet energy scale uncertainty

Jet Energy Scale uncertainty is evaluated from combination of measurements and Monte-Carlo:

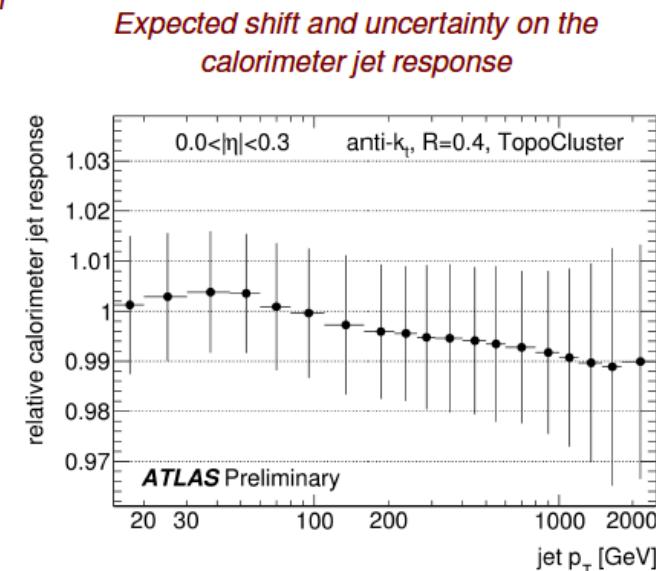
## 1. Uncertainty of single hadrons is measured in data and propagated to jets using Monte-Carlo

- Uncertainty for single isolated hadrons is obtained using  $E/p$  from isolated tracks ( $p < 20$  GeV), or from testbeam.



- Correlate single particle uncertainty with jet uncertainty using jet composition

ATLAS-CONF-2011-028



calorimeter jet uncertainty 1-3%  
(limited to  $|\eta| < 0.8$ )

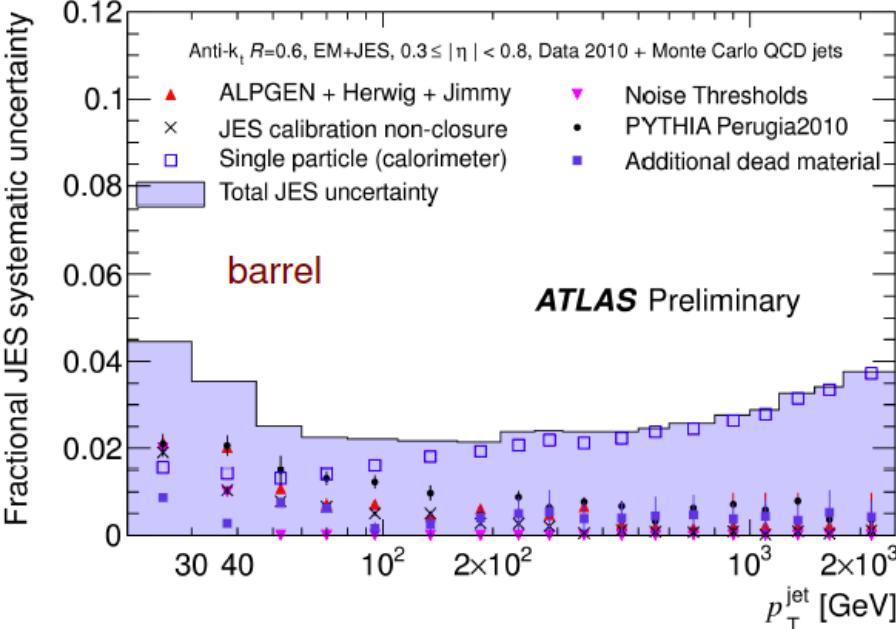
## 2. Then uncertainty is assessed up to $|\eta|=4.5$ using di-jet balance measurements

## 3. Finally combined with additional uncertainties evaluated using systematic variations of MC

- dead material, noise, hadronic shower models, soft physics effects, generators

# Default jet energy scale uncertainty

ATLAS-CONF-2011-032

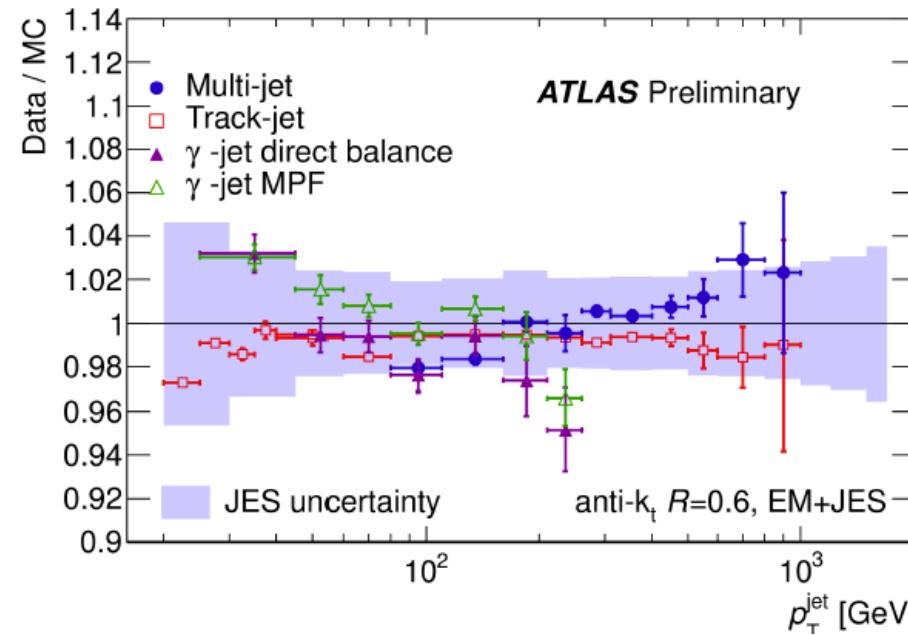


- Monte Carlo based jet energy calibration has been tested in-situ
  - ➔ multi-jet balance
  - ➔ calorimeter jet – track jet balance
  - ➔ direct gamma jet balance
  - ➔ photon balance using missing transverse momentum projection
- Obtained systematic uncertainties are in agreement with JES uncertainty estimated from single hadron response

- Summary on fractional systematic jet energy scale uncertainty as a function of jet  $p_T$

$\eta$ region	$P_T^{\text{jet}} = 20 \text{ GeV}$	$P_T^{\text{jet}} = 200 \text{ GeV}$	$P_T^{\text{jet}} = 1.5 \text{ TeV}$
$ \eta  < 0.3$	4.6%	2.3%	3.1%
$2.1 <  \eta  < 2.8$	7.1%	2.5%	
$3.6 <  \eta  < 4.5$	12.6%	2.9%	

- additional uncertainty from pile-up is estimated separately as a function of the number of primary vertices (e.g. 2 vertices five 1-2%)





# Jet energy resolution

- ATLAS default jets are calibrated with EM+JES
  - simple jet ( $\eta$ ,  $p_T$ ) approach on top of electromagnetic scale
  - well defined uncertainty ("+"), resolution can be better ("-")
- Advanced calibration schemata are available

GSC	Global sequential calibration
GCW	Global cell energy density based weighting
LCW	Local cluster property based weighting

- Jet momentum resolution measured in-situ with di-jets using bi-sector technique
- Advanced calibrations improve resolution by 10-30%
  - Monte Carlo agrees with data within 10%
- Next important step: provide uncertainties for these calibrations

